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Single-Touch to Multi-Touch System Conversion

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June 2012

A Thesis presented for the degree of
Master of Science by Research

Technology Enhanced Learning Research Group
School of Engineering and Computing Sciences
University of Durham
England

Abstract

Context: In recent years the education community has seen an acceleration in the adoption of multi-touch surfaces for educational purposes due to a number of features that these surfaces present. Some of these features include the facilitation of multi-user interaction and collaboration. However, an interesting problem exists with legacy, single-touch educational systems that lend themselves well to the features of multi-touch but have been developed with a single-user interface in mind.

Objectives: This thesis investigates how to convert an existing single-user, single-touch system into a multi-user, multi-touch system while maintaining the existing educational aims and methods. The end result is a converted application called JLens and a list of goals for converting an educational system.

Methods: This study analyses the interaction points and potential conversion factors of an existing education application and defines a set of 4 goals for converting a single-touch educational system into a multi-touch one. The final product is a converted educational system that is evaluated by representatives from the local education authorities, the educational software developers TimeMaps, multi-touch hardware developers and fellow researchers. A combination of questionnaires and observations are used for research methods and the evaluators are asked to freely explore the converted system and provide feedback.

Results: The work identifies that the majority of the evaluators responded positively to the converted system. The observations show that the users understood how to operate the system very quickly and began collaborating by sharing data without any prompt. The quantitative analysis provides evidence that the conversion was successful and all of the research goals were met.

Conclusion: This thesis has demonstrated that JLens provides a viable framework for converting existing single-user, single-touch systems into multi-user, multi-touch systems by allowing many users to navigate and explore educational applications in a collaborative way.

Declaration of Authorship

I, Charles Adams, declare that this thesis entitled, ‘Single-Touch to Multi-Touch System Conversion’ and the work presented in it are my own. I confirm that no part of the material provided has previously been submitted by the author for a higher degree in Durham University or any other University. All the work presented here is the sole work of the author.

The research has been documented or is related, in part, within the publications listed below:

- Adams, C., *Single Touch to Multi-Touch System Conversion*, School of Engineering and Computing Sciences Research Day, Durham University, 25th June 2010

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1. Introduction

The objective of this thesis is to explore the surrounding research and to attempt to find how to convert an existing single-user, single-touch system into multi-user, multi-touch.

1.1 Background

The topic of multi-touch surfaces as interaction devices has become a much debated and researched subject with work appearing as early as the 1980s (Potter, R.L., Weldon, et al., 1988). The decade between 2000-2010 saw an acceleration in the adoption and technical progression of multi-touch technology (Selker, T., 2008).

Touch screens offer many benefits over the traditional mouse and keyboard setups. They provide a means of direct interaction with the data on screen (Shneiderman, 1991), they are much faster for selecting certain sized objects (Sears & Shneiderman, 1989) and they provide an unrivalled immediacy and a rewarding sense of control (Shneiderman, 1991). Aside from the interaction benefits the solid nature of modern touch screens means that they are more hardwearing and have less moving parts. This makes them suitable for education and business purposes where extensive use may lead to the degradation of traditional systems over time.

The proliferation of new multi-touch applications, and the current processes used to design and implement these new applications, are different enough when compared to existing single-user, single-touch systems that these pre-existing systems are either completely redesigned for multi-touch hardware or discarded. These production techniques appear wasteful in terms of cost and production time especially if these existing applications have the basic structure and usability that would aid a conversion to multi-touch.

The architectural overview of a multi-touch system abstracts the hardware processes involved with detecting touches and presents a widget layer (Echtler and Klinker, 2008). An existing single-touch system could be converted to multi-touch if the elements that make up the system can be converted to run in this widget layer.

In this case the individual graphical interface elements of the single-touch system would need a multi-touch counterpart and the original aims of the system would need to be preserved after the conversion.

Throughout this thesis a case study will be presented for the conversion to be applied on and the results to be investigated from. This case study will be a converted single-user, single-touch historical education application from the Durham-based company TimeMaps.

1.2 Research Objectives

This thesis investigates the processes and effects of converting an existing single-user, single-touch system into a multi-user, multi-touch system in such a way that retains the original purposes and aims of the system but enhances the interactivity by applying multi-touch benefits.

The process of converting to multi-touch will be explored in this thesis along with the advantages and disadvantages of conversion. The evaluation and results will detail the views of a variety of experts and a selection of users with little prior multi-touch experience and will outline comments about the conversion procedure. The evaluation will discuss if the converted system aids with the learning process and if it is more engaging with the user.

It is hoped that a converted single-user, single-touch educational application will be more engaging for the users and therefore promote more time spent interacting with the application, which may increase the rate of learning.

It is expected that the use of domain experts and users with little prior multi-touch experience for the evaluation will be beneficial in the analysis as the ability to convert an existing single-touch, single-user application into multi-touch, multi-user will be useful for the industry and therefore the expert's comments will be vital for future work.

The main objective of this research is to determine how to convert an existing single-user, single-touch application into a multi-touch, multi-user collaborative application while maintaining the existing aims and objectives of the original system. The key focus of this thesis is to investigate if the benefits of multi-touch

interaction and multi-user collaboration can be applied to the existing learning objectives of a system to enhance the overall learning experience for the user.

1.2.1 Research Contributions

The aim of the thesis is to provide the following contributions to research:

- A review of the prominent literature in the area of touch screens, multi-touch, multi-user collaboration and multi-touch interactive design.
- Discussion into whether single-touch applications can be converted to multi-touch.
- Case study detailing the conversion of a historical education application from single-user, single-touch to multi-user, multi-touch.
- Results and evaluation of how experts and users with little multi-touch experience interact with the new system and if the multi-touch aspect of the converted system aids with the overall learning experience.
- Discussion of the final system as well as possible future directions that the work can be used to explore.

The research will be successful if the above points can be satisfied by the responses contained in this thesis and if the research question can be answered.

1.2.2 Research Question

The research question must summarise the aims of the thesis and the answer to it must satisfy the contributions outlined in section 1.2.1. The research question should condense the objective of the thesis which is to evaluate the procedures and outcomes of converting a single-user system to multi-touch by keeping the objectives of the original system intact but enhancing them by applying multi-user benefits.

Therefore the research question is:

“How can an existing single-user, single-touch educational system be converted to multi-user, multi-touch while maintaining the learning outcomes of the original system?”

1.3 Thesis Outline

The structure of the thesis is outlined as follows:

Chapter 2: The literature review will detail the prominent research in the areas of touch screens, multi-touch and multi-user collaboration. The work outlined here will provide the basis for the rest of the thesis and the ideas outlined in the reminder of this work will be based on the existing research outlined in this section. The end of this section will conclude by summarising the research found and how the existing work will be applied to this thesis.

Chapter 3: The Approach chapter will describe the existing TimeMaps applications and select one as a case study and present a list of goals to be met for the thesis research question to be answered.

Chapter 4: This chapter presents the research design and how the case study application will be designed. The chapter will outline how the application is converted and what the recommended software process model is for multi-touch conversion. This chapter will also explain how to identify elements of single-touch software that have conversion potential.

Chapter 5: Following the design section chapter 5 details the implementation of the case study conversion and explains the various hardware and process choices for converting an existing system.

Chapter 6: The evaluation chapter will detail the techniques used in obtaining data about the conversion process and how the existing application has been enhanced by the multi-user collaborative addition.

Chapter 7: This chapter reports the results of the final investigation and will separate them into expert results and results from users without a professional

background in multi-touch to allow a discussion of the use of the conversion as well as an expert view on the future direction of the conversion process.

Chapter 8: The discussion chapter will outline an overview of the results and detail the responses of interest from the evaluation. Trends will be identified, discussed and related back to the research question to understand if it has been answered.

Chapter 9: The final chapter presents the conclusion and future work that could be developed as a result of the findings in this investigation. This chapter will also outline potential limitations of the evaluation.

2. Literature Review

The literature review will look at the existing areas of research within the educational and technological domains surrounding this thesis. The structure of this chapter will present the high-level ideas and research and explore deeper into the research areas that are directly relevant to this thesis.

2.1 Multi-User Collaboration

The main focus of creating a system that is to be used by multiple individuals simultaneously is to understand the nature of collaboration and how to enhance the positive aspects of collaboration while preventing interpersonal tension.

2.1.1 The nature of collaboration

Collaboration over a piece of work has many advantages. Firstly, the notion of combining ideas can be considered. If many users are working together on a piece of work the problems that arise can be solved with greater quality by the combination of the rich experience and differing backgrounds of each of the individuals involved (Dooner et al., 2007).

Secondly, a simple view of time can be taken into consideration. If a piece of work takes a certain amount of time to complete with one individual then the same piece of work would theoretically take half the time to complete with two individuals (Verner, 1999).

In an educational environment it appears that collaboration is a very useful means of learning as students can work together on a project and share their insight with each other over a range of issues that arise during the course of the project. At the completion of the project the individuals that have coordinated their activities to achieve a common goal eventually provide the stability and experience that are crucial for future collaborative work to occur (Weick, 1995).

In essence these two advantages allow for a team of people to work collaboratively on a piece of work and for that work to be completed faster and with more insight when compared to the same piece of work completed by a single person.

However collaboration leads to several disadvantages that need to be carefully managed to prevent failure to complete a project. Conflicts occur frequently over the course of a collaborative project due to interpersonal tensions over the disagreement of points leading to “friction, frustration and personality clashes” (Rentsch & Zelno, 2003). This leads to distrust that affects the collaboration process and leads to the individuals unwilling to cooperate with each other.

This disadvantage can be mitigated by ensuring the learning process and the method that allows the individuals to work together is designed in a certain way. Wenger (1998) stated that by working together with a system that provides unified interaction the users have a sense of belonging and this promotes mutual engagement and prevents interpersonal friction.

2.1.2 Collaboration and technology

If the interpersonal conflicts of collaborating over a piece of work can be reduced by providing a unified interaction process then a suitable process must be explored.

Applications on multi-touch tables are being developed that allow children to collaborate on a variety of simple activities such as photo sharing.

A study by Rick, Harris, et. al. (2009) investigated the interaction between children of years 3 and years 4 when using a multi-touch table. The study focused on how children interact with the table and how they collaborate with each other to solve the tasks on the screen.

The conclusion of this study showed that the children interacted with the material more and achieved a goal faster using a multi-touch display in collaboration with others when compared to working alone on the same goal on a single-touch device.

The study goes on to show that in a multi-user, multi-touch configuration the children could complete the tasks with no discernable interpersonal issues whereas with a multi-user, single-touch system the children would often fight over who has control and the task would never be completed.

These results show that multi-touch tables aid with the collaboration process to ensure that the project is completed successfully without conflict. The effect of

these results identify that the use of multi-touch systems in an educational environment provides a unified interaction system that allows mutual engagement and therefore a suitable medium for collaboration.

2.2 Human-Computer Interaction

The ability for a user to interact with a system in such a way that the intermediary device and means of controlling the system are not part of the conscious mental process is a key part of the efficient use of a computer system. This section explores several existing ways of computer interaction.

2.2.1 Touch screens vs. mouse for interaction

Since its rise in popularity with the Apple Macintosh in 1984 up to the present day the common mouse has been the major form of interaction with a computer system (Villar et al., 2009). Although the mouse has evolved over the decades it still retains the benefits and drawbacks that existed on its introduction.

Although the common PC mouse is a popular pointing device it is certainly not the only device available. Since the inception of the resistive touch screen in 1977 many computer scientists have theorized what a refinement in this technology could bring.

Shneiderman (1991) explained: "Touchscreens are the fastest pointing device.

Touchscreens have easier hand-eye coordination than mice or keyboards."

Shneiderman also defined the significant statement: "Touchscreens have an unrivalled immediacy, a rewarding sense of control, and the engaging experience of direct manipulation."

This engaging form of direct interaction is not without disadvantages. Sears and Shneiderman (1989) identified several problems of using touchscreens compared to using a mouse including low accuracy, high error rates and arm fatigue. In the same paper a study was carried out to identify how the accuracy and speed of high-resolution target selection changes between mouse usage and non-stabilized touch gestures on a touch screen. A typical interaction that could be classed as high-resolution is the selection of the resize points on a line in a drawing application or the selection of an individual character in a document.

The study involved measuring the time taken to select a point placed randomly on a touch screen of varying sizes (1, 4, 16 and 32 pixels per side) using the mouse to select and then a touch gesture on the screen to select.

The results showed that the touch gesture is quicker than the mouse for selecting points larger than 4 pixels but the time taken to select 1 pixel point using the touch gesture is double that of using the mouse (Table 2.1).

A third implementation of touch screen software was created for this experiment in the form of a 'stabilized' screen. This screen refined the cursor location when the touch was very near to a selectable point by defining 3 regions A, B and C. A represents an area around the cursor, B represents a larger area around A, and C represents the rest of the touch screen space. For every unit of refresh time for the location determination, if the touch point moves, its new position is checked to see if it moves into another bounding box (B or C). If the touch point does not leave the bounding box A then the cursor does not move. If the touch point enters box B then the cursor moves a percentage of the distance between the current touch and current cursor position and if the touch enters bounding box C the cursor will follow the touch point as normal.

This stabilization system allows for more precise control over the cursor position for very small resolutions. As can be seen in Table 2.1 the stabilized touch screen allows for quicker selection of points smaller than 4 pixels per side when compared to the non-stabilized touchscreen with an improvement of 0.5 seconds on average for 1 pixel per side points.

	Target Size (Pixels per side)			
	32	16	4	1
Mouse	3.13 (1.28)	3.47* (1.60)	4.97 (1.98)	6.08* (1.87)
Stabilized Touchscreen	1.83 (0.37)	1.98 (0.33)	4.27 (1.27)	11.78 (4.42)
Non-Stabilized Touchscreen	1.86 (0.45)	1.93 (0.47)	4.57 (1.65)	12.28 (4.95)

Table 2.1 – Mean selection time (in seconds) per target (Sears & Shneiderman, 1989)

The disadvantage with stabilization is that the direct interaction nature of touch screens is impaired when the touch point is in bounding box A or B.

2.2.2 Finger touches as input

To understand the reason for the low precision of touch screen usage, as described in section 2.2.1, the physical method of interaction must be explored.

The use of finger gestures to interact with the system allows for direct interaction and a sense of control but the physical length and width of a finger on the contact area is far larger than other forms of interaction (e.g. a stylus or a mouse).

In an experiment by Wang and Ren (2009) the average contact area of the index finger of 12 participants was found to be 396.8 mm^2 whereas the average contact area of a stylus is around 10 mm^2 . Although input precision is lost through the relatively large size of fingers the unique shape of a finger print allows for additional input functionality on a touch screen. By drawing a rectangular bounding box around the oval shape of a finger print a calculation can be performed to find the orientation of the finger on the screen by finding the angle of the finger print against the normal (Figure 2.1).

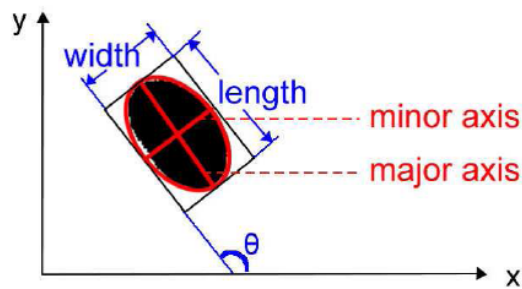


Figure 2.1 – Shape of the contact area of the finger. The area with the black colour shows the finger imprint (Wang & Ren, 2009)

The use of finger print angle and orientation is a relatively unexplored area of touch screens but when used with multi-touch displays it can facilitate several useful features including position dependent menus and information panels (Figure 2.2).

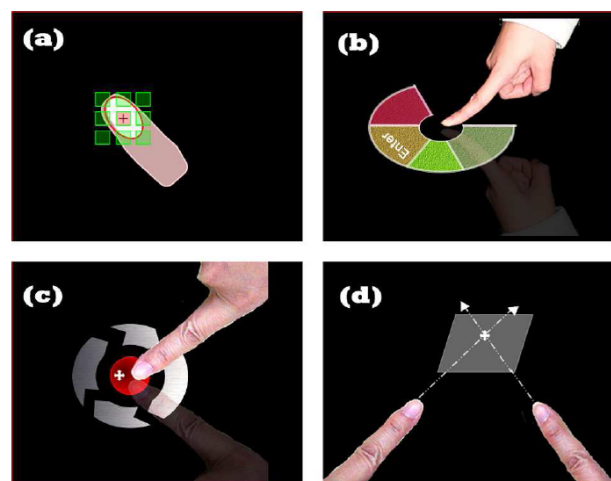
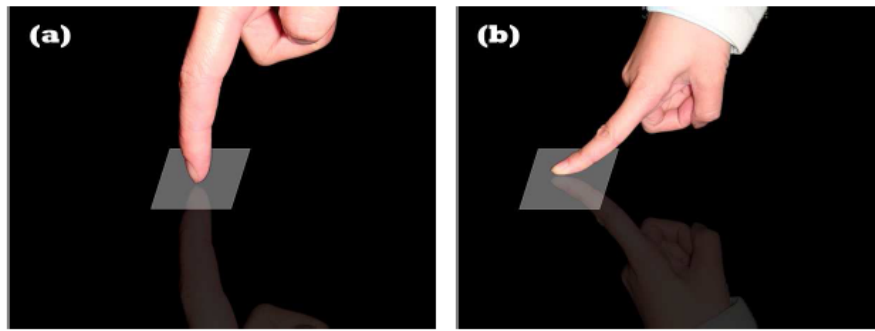


Figure 2.2 – Demonstration showing finger orientation based widgets. (a) finger combination cursor, (b) finger selector menu, (c) finger pointing stick, (d) finger cross selection. (Wang & Ren, 2009)

Wang and Ren (2009) identified two types of finger press on a touch screen: oblique and vertical touch (Figure 2.3). Oblique touch uses the flat part of the finger and has a large contact size and vertical touch uses the tip of the finger and it more precise for selecting objects. However, the smaller surface area of a vertical touch means that orientation tracking may not be as accurate when compared to the oblique touch.



**Figure 2.3 – (a) is defined as “vertical touch.” (b) shows the “oblique touch.”
(Wang & Ren, 2009)**

2.2.3 Interacting with very small objects

As described previously the contact area of a finger on a touch screen is large enough to make the selection of smaller objects difficult due to precision constraints. Two methods that can reduce this problem are increasing the size of the target or increasing the precision of the touch on the screen.

The first of these methods was studied and documented by Fortune, (1986). A Voronoi diagram is created from clusters of selectable points on a screen. The design behind this function allows for points to be extended into redundant surrounding space for improved ease of selection (Figure 2.4).

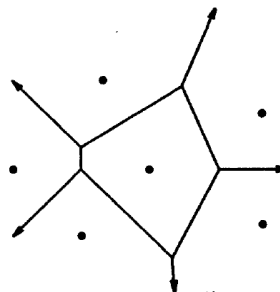


Figure 2.4 – Voronoi diagram drawn around 6 points

This is done by performing an algorithm that sweeps a horizontal line upwards and records the areas that the line intersects. This process is repeated until every region has been intersected.

This process makes it very easy to select small points as the regions surrounding the points are activated by touching anywhere in the region. However, this method has a significant disadvantage that becomes obvious with small points that are tightly bunched and are ordered in concentric rings.

Figure 2.5 shows the limitation of running a Voronoi tessellation on small clusters. When the algorithm is complete the points within the outer ring are bound with very small regions and are very difficult to select with a low precision object such as a finger. The regions enclosing the outer points are excessively large for finger selection so the result is unbalanced.

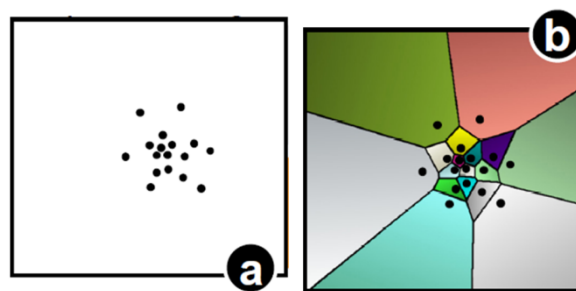


Figure 2.5 – (a) A tight cluster of points converted into (b) the Voronoi tessellation. (Baudisch et al., 2008)

A solution to the above problem is Starburst (Baudisch et al., 2008), which is a variation of the Voronoi diagram that addresses the issue of small expansion regions. A Starburst diagram is created from an initial Voronoi tessellation and the algorithm then creates “claim lines” that lead away from the clusters of points into empty screen space. These claim lines are then expanded into a clickable surface. A graphical representation is shown in Figure 2.6.

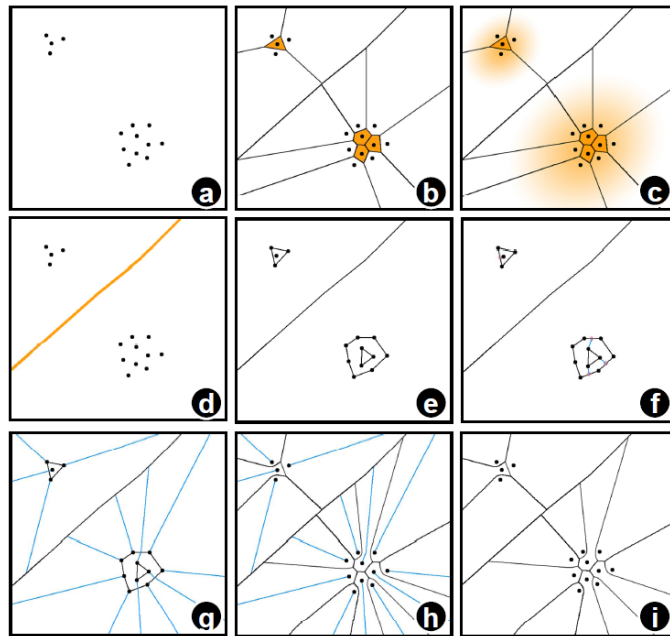


Figure 2.6 – A walkthrough of the Starburst algorithm. (a) Targets to be expanded, (b) Voronoi tessellation, (c-d) clustering of targets, (e) nested rings, (f-g) claim line construction, (h) expansion of claim lines into tiles, (i) final removal of claim lines.

(Baudisch et al., 2008)

In Figure 2.6 a visual walk-through of the Starburst algorithm is shown. 6(a) to 6(c) shows the standard Voronoi tessellation algorithm being applied to the two sets of points. This immediately highlights the problem of the small target size of inner points. In 6(e) each set of points is divided into concentric rings and those rings are joined together. The points in the inner ring are connected to the edges of the outer ring by claim lines in 6(f) and these claim lines are projected to the edge of the screen in 6(g). 6(h) shows the target boundaries being drawn around the claim lines to separate the individual targets and the claim lines are removed in 6(i) leading to the algorithms completion.

Although the Starburst algorithm shows several advantages over a standard Voronoi tessellation there are some limitations. Starburst creates regions that are long and thin, compared to Voronoi diagrams, which can be harder to select and often times have to be selected further up the region where the width increases. This is especially true with clusters of large numbers of points where the screen space allocated to each region is very small.

Although the Starburst algorithm allows easy selection of a single point from a large cluster a solution is required to improve accuracy when it is not appropriate to draw claim lines on the underlying diagram. The solution needs to be one that alters how objects are selected using finger touches.

Potter et al. (1988) detailed three touch strategies for selecting objects on a touch screen:

- Land On – is the simplest strategy as only the initial touch on the screen is registered. If a selectable object is under the finger at the time of the initial touch then it becomes selected, otherwise nothing is selected. Dragging the finger on touch has no effect to the cursor position as all further finger contact is ignored.
- First Contact – extends the Land On strategy by allowing a continuous stream of touch data. When a user initially touches the screen the position is recorded and upon dragging the finger across the screen the first selectable item will become active. The disadvantage of this system is that if a user makes contact with an unwanted item then that item is selected.
- Take Off – is similar to First Contact in that a continuous stream of touch data is recorded but a cursor appears above the user's finger. As long as the user keeps contact with the screen no selection is made but as soon as the finger is removed from the screen the position of the cursor is recorded. If the cursor is over a selectable object at that time then that object becomes active, otherwise no event takes place.

Potter et al. devised an experiment to compare the speed, accuracy and user satisfaction of each of the three strategies. 24 people each took part in 15 trials for all of the three touch strategies. Upon pressing the space bar a target appeared and the participants had to select the target using the appropriate strategy. The time was recorded and the users were required to fill in a questionnaire detailing the ease of use of each strategy at the end of the experiment. The two recorded performance metrics were time taken to select the target on appearance and the number of errors made.

Results showed that the fastest strategy was 'first contact' with an average time of 16.93 seconds followed by 'land-on' with 17.73 seconds. 'Take off' was the slowest strategy with a mean selection time of 20.92 seconds but it was also the most accurate with a mean accuracy rating of 2.25 (Potter et al., 1988).

An evaluation of this experiment could conclude that the three strategies are balanced in terms of accuracy vs. speed and that the correct strategy is highly dependent on the needs of the program employing it. 'Take off' is suitable for applications where accuracy is important but target selection speed is not. 'Land on' combined with a Starburst implementation may produce optimal results as the target area would be increased thus reducing the error rate from 5.08, as seen in this experiment, and therefore speed of selection may also increase.

Other forms of precise touch screen interaction have been described in 'High Precision Touch Screen Interaction' (Albinsson and Zhai, 2003). Some of the methods described are based on the 'Take Off' touch strategy as described previously.

The paper categorises the methods into three sets: direct zooming, cross selection and lever usage; the first method being 'Zoom-Pointing' (Figure 2.7).

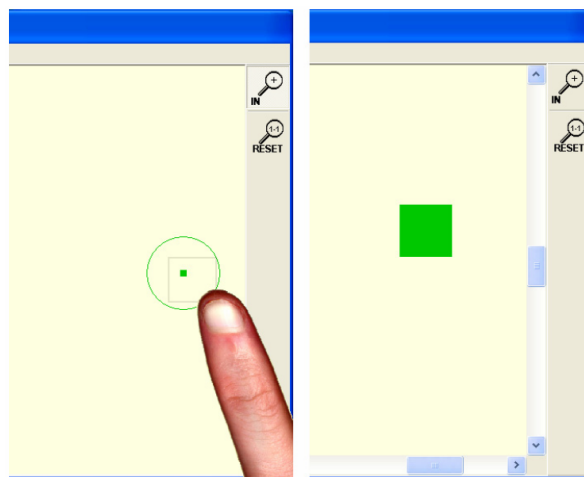


Figure 2.7 – The 'Zoom-Pointing' method. The user zooms to a sub area defined by drawing a rectangle (left). The user can then perform direct pointing at a finer scale (right). (Albinsson and Zhai, 2003).

This selection procedure is very common amongst graphic design software and it places an intermediate step between initial touch and final selection. The user activates the zoom mode, locates the area that the target is contained in and draws a rough rectangle around it. This is done by placing a finger on the screen to select the first corner of the rectangle and then moving the finger to pull the opposite corner. When the finger is lifted off the screen the screen zooms and pans to the selected area, the zoom mode is then replaced with select mode.

‘Zoom-Pointing’ has several advantages as it allows the user to change the resolution of a target therefore aiding both visual effort to locate a target and the precise motor skills required to select the target. However, this method is slow as an intermediate step is required before the selection is made. A universal issue with zooming is that the global context of the target is lost upon zooming in.

Another method that can be used for precision selection involves the use of directional arrow buttons. These buttons allow the cursor to be moved pixel by pixel after the initial selection in the area of the target. However, this method compromises some of the advantages of using a touch screen, such as direct interaction, as another control window is required to display the cursor buttons. This method is called ‘Virtual Keys’ (Figure 2.8). Although faster than Take-Off for high-precision pointing, deficiencies were discovered due to the change in eye gaze and hand movement required to activate the keys on the side panel (Albinsson and Zhai, 2003).

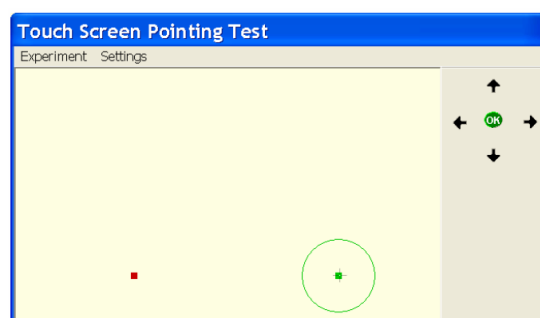


Figure 2.8 – The ‘Virtual Keys’ technique. Using the arrows on the right the crosshair is adjusted into the green target. (Albinsson and Zhai, 2003).

The 'Virtual Keys' method can be improved by moving the cursor keys from the side panel onto the crosshair with a selection button placed at the center of the crosshair. This method addresses the problem of moving visual attention and the hand away from the target area to the control keys by combining the touch area and the controls. This method is known as 'Cross Keys' and is activated when the user selects the area near to the target. The first touch displays the cross hair with the arrows surrounding and each tap on the arrows will move the cross hair by 1 pixel (Figure 2.9).

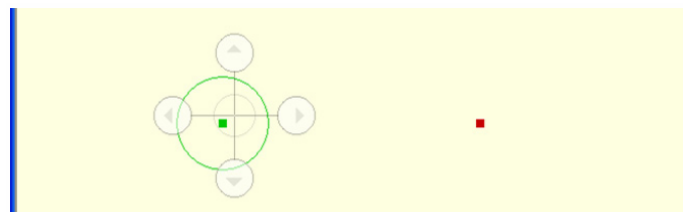


Figure 2.9 – 'Cross Keys' allows precise movement of a selection crosshair by tapping on the arrows to move the crosshair by 1 pixel in the selected direction. (Albinsson and Zhai, 2003).

Although 'Cross Keys' solves the problem of a separate control system, it abstracts away from the direct interaction properties of touch screens by requiring the user to repeatedly tap on an arrow to move an object.

An effective alternative was produced in the form of 'Cross Lever' (Figure 2.10). The goal of this method was to produce a precise selection mechanism without requiring a change in display scale.

When the user taps on the screen two crossing lines appear with movable circles attached to each of the ends. The ends of the lines can be moved so that the intersection point rests over the target. When the user is satisfied that the target is correctly intersected the centre selection point can be tapped to confirm.

Although this method is precise for selecting small targets and makes use of the direct interaction feature of touch screens it does present a few problems. It is time consuming to use and requires the user to break a two dimensional task into a series of 1 dimensional tasks.

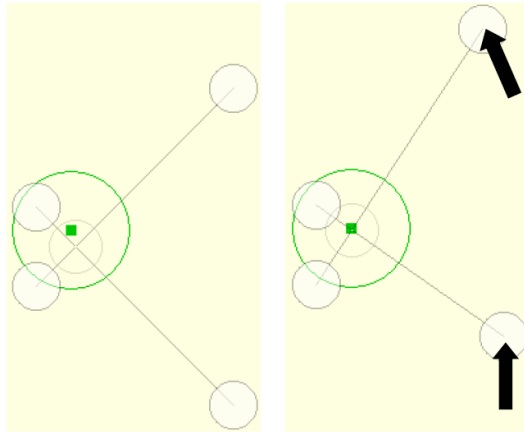


Figure 2.10 – ‘Cross Lever.’ The user places the Cross Lever near to the target and adjusts the intersecting point by moving the white circles. When the target is aligned the center circle is touched to confirm the selection. (Albinsson and Zhai, 2003).

Although ‘Cross Lever’ and ‘Cross Keys’ achieve fine control by using discrete key taps and separate movements, another solution is defined that is more fluid and continuous.

‘2D Lever’ (Figure 2.11) combines the precision of ‘Cross Keys’ and ‘Cross Lever’ by allowing the user to deploy a tear shaped handle close to the target. This handle has a pivot point near the selection end and a cross hair for precise selection. The user can drag the handle in any direction and the cross hair moves in relation to the handle around the pivot point. The pivot is placed in such a position as to allow large movements in the handle to be reflected as fine movements in the cross hair. When the cross hair is over the target the user can tap the activation circle that surrounds the selection area and the target is selected.

The main advantage of this system is that it always takes only 3 touches to select a precise object: the initial touch to deploy the lever, a touch on the handle allowing the user to drag across the screen and align the cross hair with the target, and the final touch in the activation circle to confirm the selection. This is an improvement over ‘Cross Lever’, which requires multiple touches to move the intersecting point.

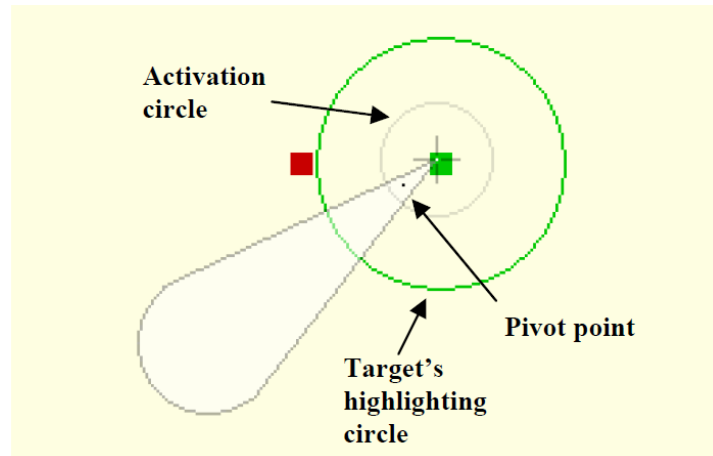


Figure 2.11 – ‘2D Lever.’ The tip of the lever can be rotated or extended about the pivot (the small black point near the tip of the lever), with precision leverage.
(Albinsson and Zhai, 2003).

An iteration of ‘2D Lever’ was also produced called ‘Precision Handle.’ In this method the real-world physics metaphor of the inverse relation between the handle and the tip was removed in favour of a simpler movement system. Any movement made by the user would be reflected exactly at the tip but at a smaller scale. A comparison between the two methods is shown in Figure 2.12.

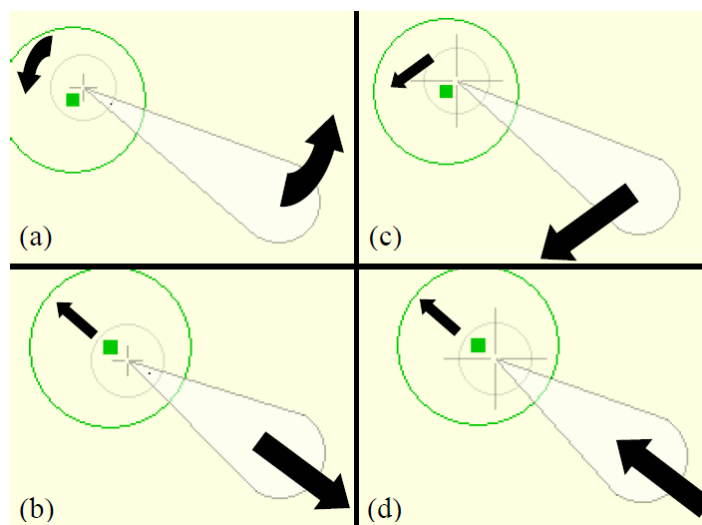


Figure 2.12 – The ‘2D Lever’ pivot point rotation (a) and translation (b) versus the ‘Precision Handle’ simplification (c, d). (Albinsson and Zhai, 2003)

In a series of experiments devised to find which of the methods was easiest and quickest to use (and therefore be the most use for the user) a test system was created with differing target sizes and selection methods. Each participant was required to select the targets as quickly as possible with each of the methods.

The rating scale used during the test was a mean subjective rating and it ranged from 1 to 5 with 1 being the most negative and 5 being the most positive.

The subjective evaluation results showed that 'Zoom-Pointing' scored the highest over the 9 marking points including: mental effort required, hand and eye fatigue, and accuracy. This was followed shortly by 'Precision Handle,' then 'Cross-Keys' (Table 2.2).

	<i>Zoom-Pointing</i>	<i>Take-Off</i>	<i>Cross-Keys</i>	<i>Precision-Handle</i>
mental	4.75	3.42	4.08	4.33
accuracy	4.50	1.67	4.00	4.08
speed	4.25	2.42	3.08	4.08
hand fatigue	3.33	2.83	3.83	3.75
eye fatigue	4.67	2.33	3.33	3.08
comfort	4.00	1.67	3.33	3.67
ease	4.33	3.08	4.08	4.17
small targets	4.58	1.08	3.92	4.00
large targets	3.58	4.75	3.92	4.50

**Table 2.2 – Mean subjective rating, from 1 (most negative) to 5 (most positive).
(Albinsson and Zhai, 2003)**

2.3 Multi-touch Architecture

Understanding the multi-touch architecture allows for the creation of a system that can run successfully when plugged into one of the levels of the architecture with no prior knowledge of the inner workings of the other levels.

2.3.1 The Architecture of Multi-touch Systems

To aid the design and implementation process of multi-touch systems an architecture has been proposed for software development. This unified

architecture allows for interoperability between different multi-touch systems and is also a predefined design template to aid the development process.

Echtler and Klinker (2008) define four different layers for a multi-touch framework to allow two advantages over existing software – first, to enable developers to use a high-level API for the creation of multi-touch enabled software. Second, to allow existing software to be used across hardware boundaries with the least change possible (Figure 2.13).

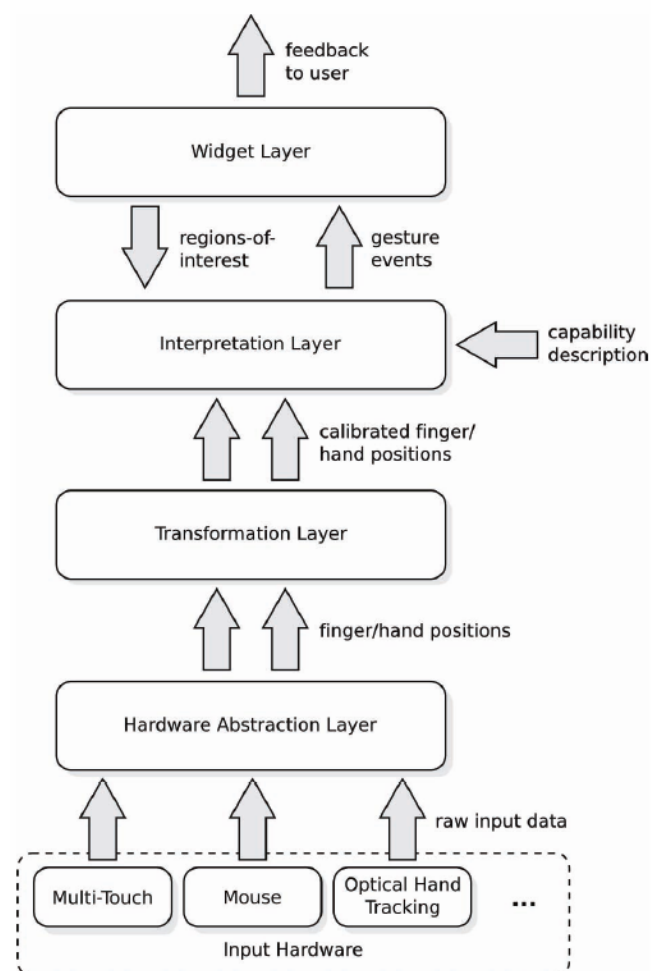


Figure 2.13 – Architecture overview (Echtler and Klinker, 2008)

The 'hardware abstraction layer' takes the raw input from the touch layer of the underlying hardware and the input data is searched for the position of hands, fingers or other objects. This data is then passed to the next layer.

The 'transformation layer' takes the low-level data and calibrates it. As some multi-touch systems are optical-based and locate hands and objects using a camera, perspective transformations need to be performed on the resultant image. A radial undistortion step needs to be carried out if the camera uses a wide-angle lens. This layer should be built in such a way that if the raw data is already calibrated the layer will not be required.

The 'interpretation layer' is the most detailed of the layers as the calibrated data packets are used to generate gesture events for the next layers. This section can be broken down into three sections: Regions, Events and Features.

Regions

A region is a polygonal area that is ordered from front to back and given in screen coordinates. It is an area in which a certain set of events will be matched. Regions can occlude each other in a similar manner to the concept of a window in common GUI environments and the foremost region has the highest priority. Regions that will never change after initial registration can be flagged as 'static.'

Events

An event is always registered to a particular region and if the specific requirements for that region are met then the event is activated. An event can be 'sticky' where the event triggered will continue even if the action that caused it moves out of its assigned region.

Features

A feature is an easily obtainable property of user input, such as the number of touch points within a region and the average distance between them or their average motion vector. An event specification will contain many features with optional conditions and if all of the conditions are met then the event is triggered.

These three entities are registered with the interpretation layer when the application is executed.

The 'widget layer' generates the visible output for the user. It receives events from the interpretation layer and registers regions with it. As the regions are already ordered, the widget layer only has to register a series of bounding boxes in the same order as the graphical widgets.

A consideration with a multi-layered system such as this is latency as data has to be sent between layers and this creates a communication cost. This system uses the User Datagram Protocol (UDP) to send the data between layers as it has a lower latency than the Transmission Control Protocol (TCP) at the cost of reliability. An experiment was set up to send time-stamped data packets to each of the hardware-independent layers and then measure the delay. 100 samples were taken and the average latency was 2.35ms with a standard deviation of 0.26ms (Echtler and Klinker, 2008). This is deemed acceptable as elements of the hardware-dependent layers have larger latencies. A camera running at 60Hz already has a minimum latency of 16.67 ms, which is far larger than the latency found in transferring data between layers.

2.3.2 The Open Sound Control and Multi-touch Protocols.

Converting physical touches on a screen to electrical signals that are then interpreted by software have been achieved in numerous ways. Several methods have been described for converting the raw data obtained into useful information that can be processed and a protocol has also been developed.

TUIO, perhaps the most common protocol, has been implemented using a system designed for communicating musical phrases across a network. This system is called OpenSound Control (OSC) (Wright et al., 2003).

OSC uses packets called 'messages' as the basic unit of data. These messages consist of an address pattern, a type tag string and an argument. An address pattern is a string that specifies the entity on the server to which the message is directed and the type tag details the data type of each argument. The argument is data contained in the message that is being sent.

For example a typical message could look like this:

Address Pattern: /voices/5/freq

Type String: integer

Argument: 4

As the address space works in a similar way to a file system; in the above example 'voices' is in the root of the address space and '5' is within it. Using this tree structure it is easy to address various locations on the server. In a musical system the above example may set the frequency of the 5th voice to the value of 4 on the server.

Although the system was originally designed to be executed on a server and was created for controlling musical phrases and pitches; the client/server architecture of the system lends itself well to other forms of message sending between a client and a server. OSC is the basis for a multi-touch protocol called TUIO (Bovermann, T. et al., 2005).

TUIO is a protocol definition that provides a communication interface between the hardware side of a touch screen and the underlying application interface. This is done by identifying several key requirements of interacting with touch screens. TUIO defines two main types of message to be passed; Set messages and Alive messages. Set messages are used to communicate information about an object's position, orientation and other states. Alive messages convey information about the current objects available to interact with on the screen using a unique session ID for each object. As TUIO is a UDP based system the possibility of packet loss is present and therefore TUIO does not define any add or remove messages. The receiver compares sequential alive messages to determine if an object should be removed or not.

In addition to the Set and Alive messages an fseq message is defined to tag each update with a unique frame sequence ID.

OSC is used to define the syntax of messages created by TUIO. For example:

```
/tuio/[profileName] set sessionID [parameterList]
/tuio/[profileName] alive [list of active sessionIDs]
/tuio/[profileName] fseq int32
```

(Bovermann, T. et al., 2005).

Several parameters are defined that are important for manipulating objects on a multi-touch screen (Table 2.3 – Semantic types of Set messages (Bovermann, T. et al., 2005)). Although the messages sent from the client simply request current information from the server (e.g. id, position and angle) some of the responses require additional processing on the server side as they are derived from other factors (e.g. speed and acceleration are processed using timing information). This process is quicker as the raw timing information does not need to be sent to the client, which would cause additional latency and the possibility of packet loss leading to erratic control of the touch screen.

s	sessionID, temporary object ID, int32
i	classID, fiducial ID number, int32
x, y, z	position, float32, range 0...1
a, b, c	angle, float32, range 0..2PI
X, Y, Z	movement vector (motion speed & direction), float32
A, B, C	rotation vector (rotation speed & direction), float32
m	motion acceleration, float32
r	rotation acceleration, float32
P	free parameter, type defined by OSC packet header

Table 2.3 – Semantic types of Set messages (Bovermann, T. et al., 2005).

Several profiles are defined that apply to most multi-touch screens (Figure 2.14). These profiles define the interaction with 2D and 3D objects. If one of the profiles does not meet the system requirements then a ‘raw’ profile can be used that sends the raw sensor data. A ‘free-form’ profile is defined allowing a user defined set of parameters to be transmitted.

```

2D Interactive Surface
    /tuio/2Dobj set s i x y a X Y A m r
    /tuio/2Dcur set s x y m r
2.5D Interactive Surface
    /tuio/25Dobj set s i x y z a X Y A m r
    /tuio/25Dcur set s x y z m r
3D Interactive Surfaces
    /tuio/3Dobj set s i x y z a X Y Z A m r
    /tuio/3Dcur set s x y z m r
raw profile
    /tuio/raw_[profileName]
    /tuio/raw_dtouch set i x y a
custom profile
    /tuio/_[formatString]
    /tuio/_sixyP set s i x y 0.57

```

Figure 2.14 – The defined profiles of TUIO (Bovermann, T. et al., 2005)

The combination of the OSC protocol and the defined parameters of multi-touch screen usage have lead to the creation of TUIO which supports the communication of the object layer and the interaction layer using client/server architecture. Although this design allows for the interaction layer and the object layer to be in the same location it also allows for the data to be transferred over a network allowing for distributed multi-touch interaction.

2.4 Gestural Control

A consideration with the creation of multi-touch systems is how to make the interaction process with the multi-touch screen more natural. As multi-touch systems are a form of direct interaction a series of natural gestures have been proposed to improve the user experience.

Current tested methods for interaction base the screen display as a large image of a sheet of paper. Using this analogy the objects on the screen can be moved by pressing a finger onto the screen and moving it in any direction; this defines a panning operation. If two fingers are placed on an object the system will 'stick' the fingers to the object so at the end of any translation the two reference points will be orientated to the fingers. This allows for more advanced interactions such as rotations (by rotating the fingers around the center point) and zooming (by moving

the fingers further apart) (Hinckley, 1998). More control can be had by using another pair of fingers and placing both sets on each corner of the object (Kruger, et al., 2005).

The advantage with this method is that it applies several real-world physics ideas to the system to aid with understanding and immersion process. This method for control can be expanded to include gravity and friction where if an object can be moved in an unbalanced way by touching around the center point (Figure 2.15).

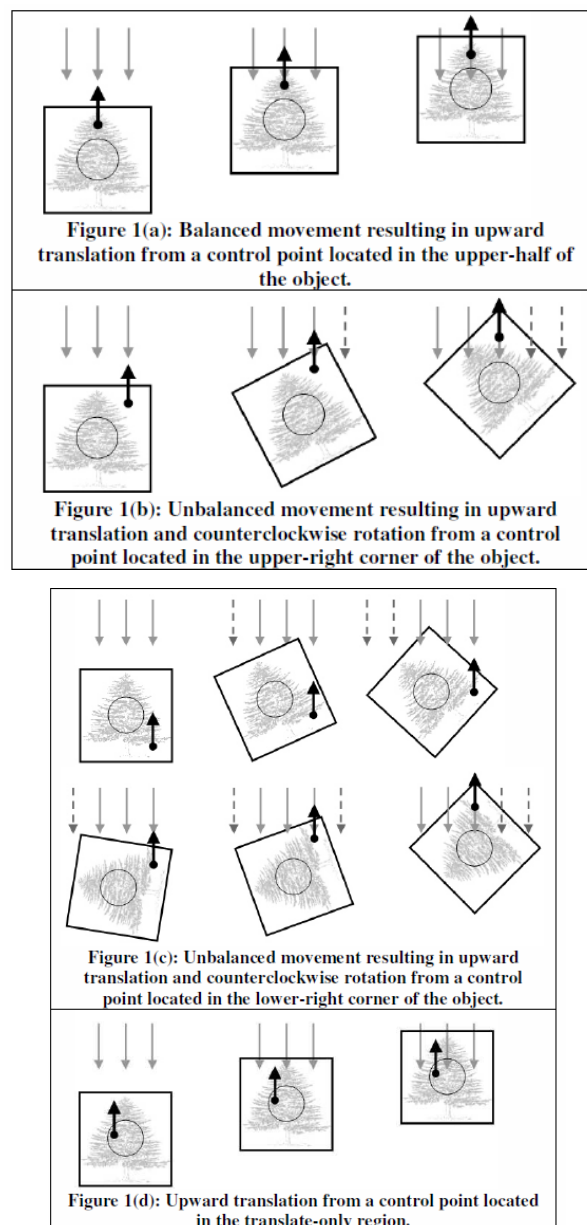


Figure 2.15 – Illustration of integrated rotation and translation (Kruger, et al., 2005)

Research in this area has gone further to include studies into controlling systems with multi-touch hand gestures as well as foot gestures using a Wii Balance Board (Schöning et al., 2009) (Figure 2.16). A combination of the two allows for easier control over more complex environments such as full 3D movement and controlling specialist software (e.g. a Geographical Information System). Schöning et al designed a 3D map system where the user can pan and rotate the map using gestures on the screen but the user can zoom in and out by altering their balance on the Balance Board. Initial evaluation showed that the use of feet allowed for a faster and smoother interactive process but at the cost of comfort.



Figure 2.16 – Foot waiting gesture. People waiting often stand on the sides of their feet. This interaction could be used to return to the home screen on an application. (Schöning et al., 2009)

2.4.1 Multi-touch scrolling

A classic form of scrolling in a multi-touch application is to place a single finger or two fingers on the item to be scrolled and then moving the finger up or down the screen in a flick motion to swiftly scroll the item; or in a slow motion for finer control over the scroll (Lao. S., et. al., 2009).

A problem occurs if the item to be scrolled is nested within another element that uses the same scrolling gestures for a translation effect. In this instance it may be more suitable to find a separate window to use for scrolling purposes. Or a multi-touch scroll bar.

A multi-touch system DTLens (Forlines, C., 2005), uses a resize handle in the lower right of a window that allows the user to zoom into and out of an image by touching and dragging the scroll bar.

This is a useful addition as the zoom slider affects the items nested within an element (Figure 2.17).

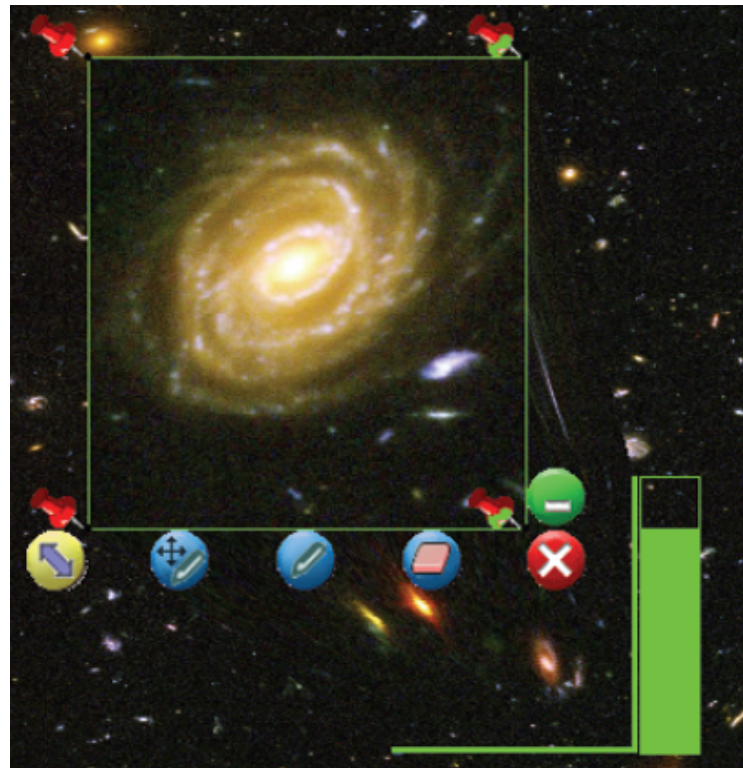


Figure 2.17 – DTLens showing the scroll bar in the bottom right of the window. The user can touch and drag the scroll bar to adjust the zoom parameter in the main window. (Forlines et. al., 2005)

2.5 3D Interaction

A potential issue arises when the user wishes to manipulate 3D objects using a multi-touch system and still keep the smooth natural interaction process. A 2D object can be manipulated by rotation, zooming and panning – tasks that can be easily performed using two hands. The notion of ‘Degrees of Freedom’ (DOF) can be introduced that defines which planes of movement an object can be moved in. A 2D object can be moved in 3 DOF, as described above, but a 3D object requires 6 DOF:

1. Moving up and down
2. Moving left and right
3. Moving forward and backward
4. Tilting forward and backward
5. Turning left and right
6. Tilting side to side

(Martinet et al., 2009)

Hancock et al. have defined a form of 3D interaction by using a shallow-depth z plane in a 3D environment where the 3D object can be rotated about the x and y axes by touching it with a finger and moving the finger over the interactive surface. The standard interactions performed on a GUI are deemed shallow depth as windows can be stacked on top of each other and riffled through which makes this method advantageous for users of these systems.

A 5 DOF movement can be achieved by a single touch by pinning the touch action to the object through point of contact. Touching the point works like a sticky finger in that the contact point will rise to the surface. Rotating the object requires the user to touch a slide and drag it. A retouch may be required to keep rotating the object to view occluded sides (Figure 2.18) (Hancock et al., 2007).

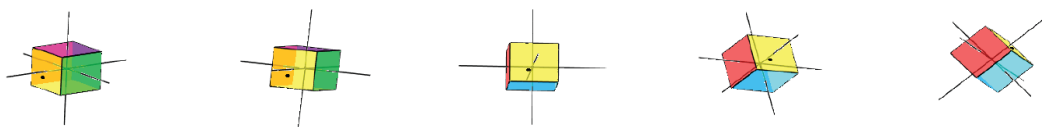


Figure 2.18 – A sequence of motion using one-touch interaction in shallow-depth 3D. The black dot represents the point of contact of the user's finger. (Hancock et al., 2007)

Although this method allows the user to rotate an object in any direction it is often necessary to place constraints on the rotation such as movement in one plane only. This can be done by drawing a doughnut around the shape that allows rotation around that axis only by touching and dragging around it.

Five or six DOF can be achieved by using only 2 points of contact. The first point will allow for free rotation and translation in the x and y-axis as described above but a second point will add the ability to pitch and roll. Two contact points also allows for movement in the z-axis by changing the distance between them in a similar way to zooming 2D pages.

By introducing a third touch point pitch and roll adjustment are included in addition to the two previous movements. Although this allows for greater control over the object the combination of each touch point is immediately quite confusing for a user without practice of each individual point.

An empirical study was carried out to determine how each touch input affected speed, accuracy and user preference. The results showed that three-finger touch is faster (average 13.3s completion time) than two-finger touch (average 15.7s completion time), which is faster than one-finger (average 18.9s completion time) (Hancock et al., 2007). The same trend was seen with incomplete trials with the three-finger input obtaining the lowest number. On the user preference questionnaire the three-finger input obtained the highest score, on average, with a higher preference seen on ease-of-use and expectation compare to the other inputs.

Another approach for 3D interaction examines how a traditional desk is used. 2D objects can be manipulated, such as paper, as well as 3D objects, such as pens and books. Knowing this an analogy can be assumed for multi-touch tables that allows the use of tangible objects for interaction (Hancock et al., 2009).

A device has been created, TableBall, incorporating a trackball that allows for 5 DOF – 3 DOF is tracked by the position and rotation of the device on the table and 2 DOF are provided by the trackball. Placing the TableBall on an object selects it and sliding and rotating the device across the table also moves the object in relation. The trackball on top of the device allows for precise object rotation around the x and y axis.

A user study was carried out to further explore the useful extend of tangible interactions. The users were required to dock a 3D pyramid with another pyramid

so that the vertices matched up. The pyramid was considered docked if the vertices were aligned to within 6cm (126 pixels).

The results showed that the users preferred using direct touch instead of TableBall. Direct touch was quicker than using TableBall for planar movements (where the object was only moved over a 2D area). Completion times for planar movements were 6.5 seconds for direct touch and 15.2 seconds when using TableBall.

However, when full 3D rotation and translation was required the TableBall technique was slightly faster with a completion time of 17.1 seconds as opposed to 17.6 seconds for direct touch.

2.6 JLens

The system created for this thesis is known as JLens and combines facets of the above literature, relating to interaction, to provide a way of interacting with a static image using key multi-touch methodologies.

When the system has loaded the user is presented with a main menu that is activated by touch. When the user presses 'Load Lens' a lens will appear in the centre of the screen for manipulation (**Figure 2.19**)



Figure 2.19 - Loading a lens.

Another touch on "Hide Menu" will cause the main menu to disappear to allow a better view of the underlying image. If the user presses two opposing corners simultaneously then the menu will return (Figure 2.20).



Figure 2.20 – Revealing the Main Menu.

When a lens is loaded it can be manipulated in various ways. By touching the lock icon (Figure 2.21) the image in the lens will remain stationary when the lens is moved around the screen. By pressing the lock icon again the image in the lens is unlocked and will follow the underlying image. To rotate the lens the user can place two or more fingers on the lens and rotate them clockwise or anti-clockwise to change the orientation of the lens (Figure 2.22).



Figure 2.21 - Locking and unlocking the lens.



Figure 2.22 - Rotating the lens.

To change the zoom level of the lens the user can place a finger on the red bar to the right of the lens and drag down to increase the size of the bar and decrease the zoom level, or drag up to decrease the bar and therefore increasing the zoom accordingly (Figure 2.23).



Figure 2.23 - Zooming the lens.

2.6 Summary

In conclusion, the field of multi-touch is ever growing and becoming more prominent. This is due to the interactive nature of multi-touch devices compared to traditional input types. Multi-touch is an extension of the single-touch mouse, as it possesses many similarities such as quick input. Multi-touch tables allow for direct input as the images and on-screen content can be interacted with using fingers therefore bypassing the need of a separate device to do this.

The weaker area of multi-touch compared to the use of a mouse is accuracy. However, much research has been done in this area and the results can be seen above. Another area that multi-touch excels in includes multi-user collaboration as many fingers can be detected on the screen at once and therefore the fingers can belong to different users. The benefits of multi-touch displays as collaborative

devices are vast allowing for different social interactions and the easy sharing of information and ideas.

3. Approach

This chapter will firstly describe a case study based around the historical mapping company TimeMaps (2009) and secondly define a set of goals that takes existing research as a foundation and aims to build upon it to ensure that gaps can be defined and possibly addressed. The chapter will end with a summary of the goals and this will lead into the design section.

3.1 Case Study: TimeMaps

TimeMaps are a Durham-based educational software company that specialise in creating historical mapping applications for schools. The company has a range of products that aim to teach the users about a specific area of history by presenting the users with a map of the country or continent of interest and a timeline slider (Figure 3.24). The slider allows the user to advance the map through history and observe the changes on the main map (Figure 3.24 (a)).



Figure 3.24 - Example TimeMaps application presenting the user with a historical timeline of the Black Death. (a) Shows the timeline slider that can be adjusted by clicking on the two arrows. (b) Shows an example of a pop-up information window that appears after selecting an information point.

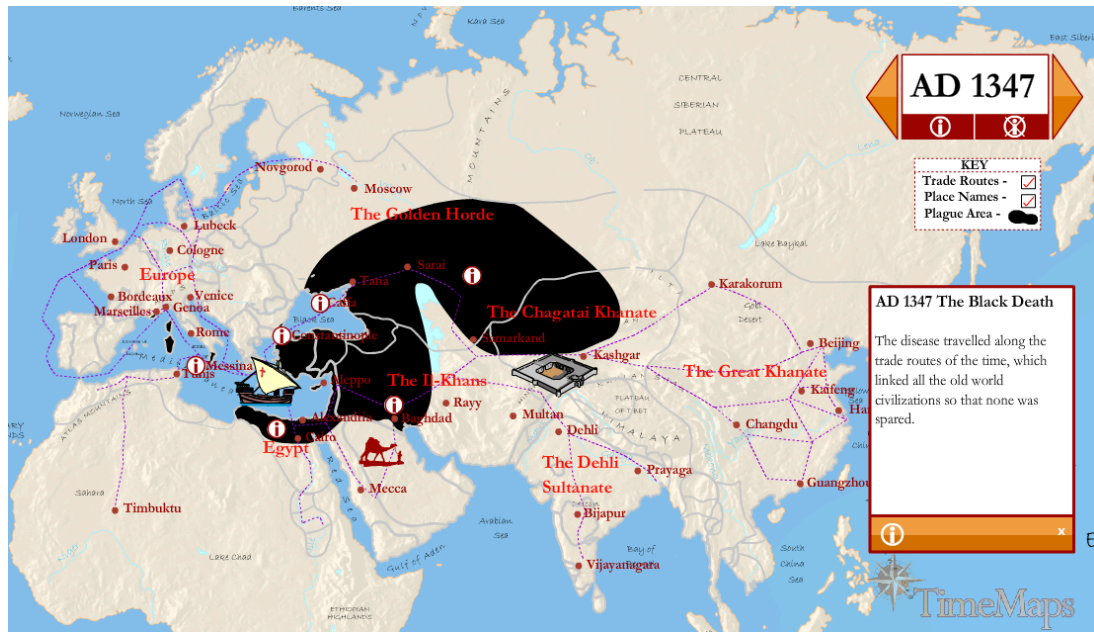


Figure 3.25 – Screenshot of the same Black Death TimeMaps application as in Figure 3.24 with the timeline advanced by a year. Note the change of the map image and the different placement of the information points.

3.1.1 Interaction Design

The applications TimeMaps develop are for single-user, single-touch use and can be installed on a typical PC and are interacted with using a mouse by one user.

Although the software content lends itself to group work and discussion only one user can interact with the map or advance the timeline. This makes the applications suitable for a classroom-based discussion where it is displayed on a large screen and controlled by a teacher but for pupil centred group work a single pupil would always have control which may lead to collaboration difficulties (Section 2.1.1 – The nature of collaboration).

At each year on the timeline the map contains several information points that the user can click on with a mouse to reveal a pop-up box information box (Figure 3.24 (b)). These information boxes may contain text, audio or video clips and when an information box is open that area of the map is occluded and only one box can be displayed at any one time. The information box is a fixed size but as the content displayed may be short passages of text there is a large percentage of unused space when these boxes are open.

The notion of a pop-up window containing further detail is useful in an educational environment as it allows the user to explore an area and obtain detailed notes about a region of particular interest.

A typical usage of this concept from the TimeMaps software is that a user could be presented with a view of Europe and Asia showing the spread of the Black Death over the period of a several years (Figure 3.24, Figure 3.25). The user could select information points to understand how the Plague affected small villages and individual people therefore allowing the user to understand the scale of the spread. This added depth increases the interactive appeal of the system and enhances learning by encouraging the user to spend more time exploring. The learning goals of this application are centred on teaching the user about the causing factors of the Black Death and visualising the speed and the extent of the spread of the disease.

3.1.2 Potential multi-touch conversion

The research question defined in section 1.2.2,

How can an existing single-user, single-touch educational system be converted to multi-user, multi-touch while maintaining the learning outcomes of the original system?,

can be split up into several interaction points that must be investigated for this thesis to be a success.

This section will use the description of TimeMaps applications in section 3.1.1 as a basis and identify the individual interaction points of a single-touch TimeMaps application that need to remain after a multi-touch conversion.

The interaction points outlined in 3.1.1 can be summarised as follows:

1. The application always displays a map image in the background.
2. The map can be advanced using the timeline controls.
3. Each period in time displays information points scattered in different locations.
4. Clicking on these points with a mouse displays a pop-up information box.

5. The information boxes can display a variety of media about the area around the information point.
6. Only one pop-up box can be displayed at any time until it is closed or another information point is selected.
7. Each application teaches the user about a specific event or time in history.

If this existing application is to be converted to a multi-user, multi-touch system then the points listed above must be altered to allow simultaneous multi-user interaction.

Certain interaction points must remain after the conversion process to maintain the original interaction methods of the TimeMaps applications. The static background image, the information points and the pop-up boxes are key tangible elements that make a TimeMaps application; but the learning outcomes must be maintained so that the multi-touch additions enhance the system but do not detract or change the learning outcomes.

The following goals isolate the important aspects of an existing TimeMaps application to ensure that they are converted to multi-user, multi-touch successfully.

3.2 Goals

The 4 goals featured here will comprise of several ideas and theories from the literature, as reviewed in section 2, and will become constituent parts of the research question. If the end result of the thesis meets these 4 goals then the research question can be considered answered.

3.2.1 Static image collaboration

One of the issues when users are presented with an image to collaborate with is how to interact with it without altering the view of the image for the other users. For example, in a classroom environment an existing TimeMaps application could be presented to children to explore. This application would be based around the view of a single map image and the children would be asked to work together to achieve a goal. The first problem with this system is that only one child could

interact with the map at once and any changes that the child makes to the map must be interpreted by the next child before they can add to the discussion. Any subsequent children that use the system could alter the map and the collaboration aspect is diminished. The ideal solution would allow all of the children to work with the application at the same time without altering the map view for each other. The following section will describe the benefits and difficulties of collaborating over an image.

Dooner (2007) states that the combination of the previous, rich experiences of the individuals collaborating over a piece of work allows for high quality solutions to be produced. This statement combined with that from Weick (1995), which explains that after the completion of a collaborative project the individuals have gained knowledge and experiences that are crucial for future collaborative work, highlights that the first goal of this research is to understand how to collaborate over an image. By collaborating over a static image the users will be able to achieve a common goal with a high quality solution and the image will provide a means of unified interaction therefore promoting mutual engagement and preventing interpersonal friction (Wenger, 1998).

The difficulty in collaborating over a single image is the static nature of the image. An image can be translated over x and y-axes and it can be zoomed into but any movement affects the whole image and the view of an individual will be affected by the actions of another. A method needs to be produced that allows for the independent ability to take a snapshot of an area of an image and rotate and translate that area. The ability for many snapshots to be created onscreen for multiple users is a requisite.

The first goal of the research is to identify how multiple users can collaborate over a single static image without altering the view of the image for the other users by using the snapshot tool or 'lens.' Thus this concept is summarised as:

Goal 1: Allow multiple users to collaborate over a single static image without altering the image for the other users.

3.2.2 Occlusion

One problem with using a secondary tool to allow the multi-user collaboration over an image is the problem of occlusion. In an image-based application the background image will provide the users with a reference to know which areas to explore and where areas of interest are located. The tool that takes the snapshot of the underlying image would consist of at least a main window and buttons to allow the user to navigate and interact with their individual snapshot. As more of these windows are drawn onto the screen, the background image would become occluded and therefore the main point of reference for the users would become obscured. This is one disadvantage to using a secondary tool for interaction but this disadvantage can be minimised by exploring the usability of onscreen multi-touch buttons and specifically the smallest point that can be selected by the average finger size.

Sears & Shneiderman (1989) identified that selecting an object is quicker and less prone to error when using a touch screen if the object is greater than 4 pixels per side and the touchscreen speed is significantly quicker when using an object greater than 16 pixels per side (Section 2.2.1 – Touch screens vs. Mouse for interaction). Picking accuracy is largely dependent on both the size of the contact area of the finger and the type of touch applied to the screen. A user touching the screen with a vertical touch would apply a smaller contact area to the screen than a user applying an oblique touch however an oblique touch is more comfortable over long periods of usage (Wang & Ren, 2009) (Figure 2.3).

The above literature outlines that the interface that allows the users to interact with an image should be designed with buttons that are within these constraints for speed of selection and minimal occlusion.

One possible solution to the selectable elements is to use very small objects (less than 2 pixels per side) but incorporate Voronoi tessellation (Fortune, 1986) or the Starburst algorithm (Baudisch et al., 2008) (Section 2.2.3 – Interacting with very small objects). In theory this would allow for very small elements to be used in the interface but the expansion of the claim lines for the tessellation (Figure 2.6) would cause more occlusion for the other users and the background image.

The second goal of the research is therefore to minimise occlusion from the interaction techniques but to maximise usability in terms of speed of selection of buttons and the reduction of errors from these selections. Thus this concept is summarised as:

Goal 2: Minimise the occlusion caused from an interaction tool but maximise the usability of the interaction tool.

3.2.3 Precision selection

Goal 1 assumes that the image displayed on the screen has a fixed resolution equal to the monitor it is being displayed on and that zooming into the image would provide the user with nothing more than an inflated view. However images, especially maps, can have a resolution larger than the screen size. In a current TimeMaps application the user is presented with a fixed continent-sized map of an area of the world with several information points scattered over the landscape. When a user selects one of these points some information appears detailing the point of interest. So although the user is not zooming into the map they are receiving information about a small part of the map. This is a very useful feature for understanding how small countries and events fit into a world-wide incident; but in the current form it is not a suitable means of interaction for multiple users because the pop-up information could occlude other information points and be orientated so only one user could read it.

Albinsson and Zhai (2003) proposed several ways for interacting with small points on touch screens that could be applied to selecting an information point. The “Virtual Keys” and “Cross Keys” methods would be unsuitable for this thesis as they rely on a separate control panel that adds to the occlusion problem discussed in 3.1.2. An appropriate solution would be “Zoom Pointing” as the user can zoom into a small point and therefore uncover an area of interest. The combination of this method with the notion that a map is an image of large resolution means that the user could potentially zoom into an area of interest and view the information in one movement instead of selecting an information point first. In an example a TimeMaps application user could zoom down to a particular information area and

the information box would appear during the zoom at a defined zoom level. This would prevent occlusion of other items.

The “Zoom Pointing” method provides a suitable solution to zoom into a point however the interface design suggested makes the method suitable only for single-users but by combining the “Zoom Pointing” method into the individual lens tools as described in section 3.1.1 the users will be able to zoom into the image and interact with it without altering the view for the other users. By combining “Zoom Pointing” the issue of occlusion is also managed as the zoom pointer interface size is reduced into each lens.

The design could be improved by added features from DTLens (Forlines et al., 2005). By adding a vertical scroll bar that can be scrolled up or down using one finger the user has control over the degree of zoom without taking their fingers off of the lens to press buttons. The smooth scale offered by using a scroll bar could also improve the flow of the zoom as this could be achieved in smaller increments.

The third goal is to allow the users to zoom into an image of larger resolution than the display to uncover areas of interest without affecting the image for the other users. Thus this concept is summarised as:

Goal 3: Allow the lens to be zoomed into a point for precision selection without affecting the background image.

3.2.4 Maintain the learning outcomes

Converting an existing TimeMaps application into a multi-user, multi-touch application by applying the above 3 goals will alter the interaction of the system entirely. A fourth goal is to ensure that the learning outcomes of the new application match those of the existing system. Maintaining the learning outcomes of the existing system but enhancing the system by adding multi-user collaboration and multi-touch is one of the aims of this research.

TimeMaps applications provide the learning from pop-up windows containing information at a particular point. As this information is going to be transferred into the zoom function of the lens the major source of the learning outcomes is maintained. For other application conversions the existing system needs to be

reviewed and understood to find the areas that provide the information for the learning outcomes.

The fourth goal is to ensure that the educational learning outcomes are maintained when the system is converted to multi-touch. Thus this concept is summarised as:

Goal 4: Ensure the original learning outcomes are maintained after the conversion process.

3.3 Summary

The four goals highlighted above combine areas of the reviewed literature and represent the main components to answer the research question. If the system is converted and meets all of the above goals then it can be considered a success. The goals are not presented in order of importance but the failure to meet a single goal would most likely lead the failure to meet one or more of the other goals.

In summary the goals are:

1. Collaborate over a static image.
2. Prevent unnecessary occlusion by the lens
3. Allow the lens to be zoomed for precision selection.
4. Maintain the learning outcomes through the conversion process.

In later chapters the goals will provide a target for the design, implementation and evaluation to ensure the final results meet the goals and therefore answers the research question.

4. Design

This chapter will discuss the interaction design and the different elements that make up the design of the system – named ‘jLens.’ The use of every interaction element will be discussed and justified within this chapter.

To create a successful interactive system a focus must be placed on using good human-computer interaction principles and good interaction design principles.

Interaction design is the process of studying how users can interact with a system and how they can manipulate elements on screen easily with little documentation or designer input.

For the interaction to be easy and non-invasive for the users the elements on screen must be designed in such a way that they correlate to real world objects such that the users can create mental models of the on screen items (Borchers, 2000). With this notion, the elements on display in the application will be layered on top of each other giving the appearance of a stackable interface. In a real-world situation where a table could be covered in layers of paper an individual can use their hands to slide the paper around. This example can be extended and individuals can use a flicking action to throw the paper across to the other side of the table. In a similar manner the interface of the jLens application will mimic this real-world property to enable a more fluid interaction and a suitable analogy of real-world physics. This method of identifying usability issues to focus on the ease for new users to accomplish tasks is called cognitive walkthrough (Rieman, et.al., 1995).

4.1 Design Considerations

The selected methods for designing the system are important to ensure the system is created within the scope of the timeframe and that all of the defined goals are implemented. This section will outline the software process model and system structure to ensure the creation of an end-product that meets the goals of this research.

4.1.1 Software Process Models

Many different process models exist for software design such as the waterfall model. In this model each level of software development cascades from one level down to the next. Other models include the Spiral model which follows a risk-driven approach where the development cycle is represented as an expanding spiral and the radial dimension denotes cumulative development costs (Boehm, 1987).

This thesis is based around prototyping and the ability to alter the original design at any stage. This is necessary as regular meetings with TimeMaps will introduce new ideas and directions for the research to explore. Goal 4 states that the original learning outcomes must be maintained after the conversion and therefore regular meetings with TimeMaps must take place to ensure they are happy that no educational value has been lost at any stage. The flexibility required for the research needs an altered type of software process model that allowed for small constant changes as a result of input from the main stakeholder. Therefore a decision was made to use the Incremental Development Model (Figure 4.26).

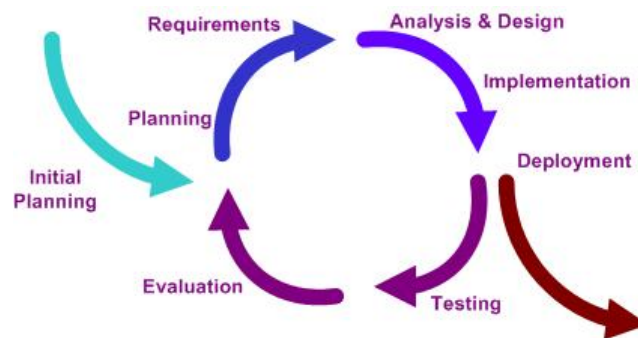


Figure 4.26 - Incremental Development Model (Hung, 2007)

The incremental model is a form of the iterative design process where the software is developed through repeated cycles based on testing and feedback at the end of each stage of development. This feedback provides the basis of changes to the system and possible new directions for the subsequent stages of implementation. This model is also a benefit because the main stakeholder has little experience in specifying the software requirements and through regular updates and reviewing the system, requirements can be changed in an ad-hoc manner.

The main stakeholder will be updated with the progress of the system at the end of every cycle via regular discussions and blog posts. Feedback will be received and added to the next cycle until the aims of the system have been reached and the stakeholder is happy that no more changes need to be made.

This model also allows for other influences to affect the design process at the end of each iteration. As each iteration will take a certain amount of time (and in total potentially take longer than using a waterfall design method) research and questionnaire-based evaluative feedback can be gained, as well as stakeholder feedback, to ensure that the final product is based on multiple feedback inputs at each stage and is therefore more thorough. This also means that the critical requirements are developed first and any further functionality can be added to the system at a later date.

Benefits to using the incremental model of development include:

1. Customers do not have to wait until the entire system is delivered before they can gain value from it. The first increment satisfies their most critical requirements so they can use the software immediately.
2. Customers can use the early increments as prototypes and gain experience that informs their requirements for later system increments.
3. There is a lower risk of overall project failure. Although problems may be encountered in some increments, it is likely that some will be successfully delivered to the customer.
4. As the highest priority services are delivered first, and later increments are integrated with them, it is inevitable that the most important system services receive the most testing. This means that customers are less likely to encounter software failures in the most important parts of the system.

4.1.2 Architectural Models and System Structure

As discussed previously, the system will be designed using an incremental approach because the user needs to provide constant feedback during the design stage. Also, the system should be designed in such a way that the feel of the system (component parts) remain the same but the subject can be changed depending on the required use. For example in an education setting the system could be used for

many subjects, such as biology and history. In these two different uses the system will work in the same way but the maintainer/user can change specified elements to alter the use in context. This is known as a framework.

The system will be built as a plug-in for the “SynergyNet” project, which is a Java-based framework for creating multi-touch applications for education purposes. SynergyNet is product of the Technology Enhanced Learning department at Durham University (TEL, 2010). SynergyNet allows a developer to create multi-touch applications by focusing on the interface and how users can interact with the application at a software level. The hardware communication between the actual table mechanism and the software is abstracted allowing the developer to call upon event listeners for finger presses, dragging and releases and their associated functions. This allows SynergyNet and all applications created using the framework to be easily ported to other multi-touch table designs with no changes required at application level.

This framework allows for rapid prototyping and development, which are important factors in an iterative design process such as this. The users will be providing constant feedback and will require quick turnaround times with the releases.

The system itself will be split up into 5 separate classes that provide individual services and form the main configuration of the system when combined. These classes are shown in **Figure 4.27**.

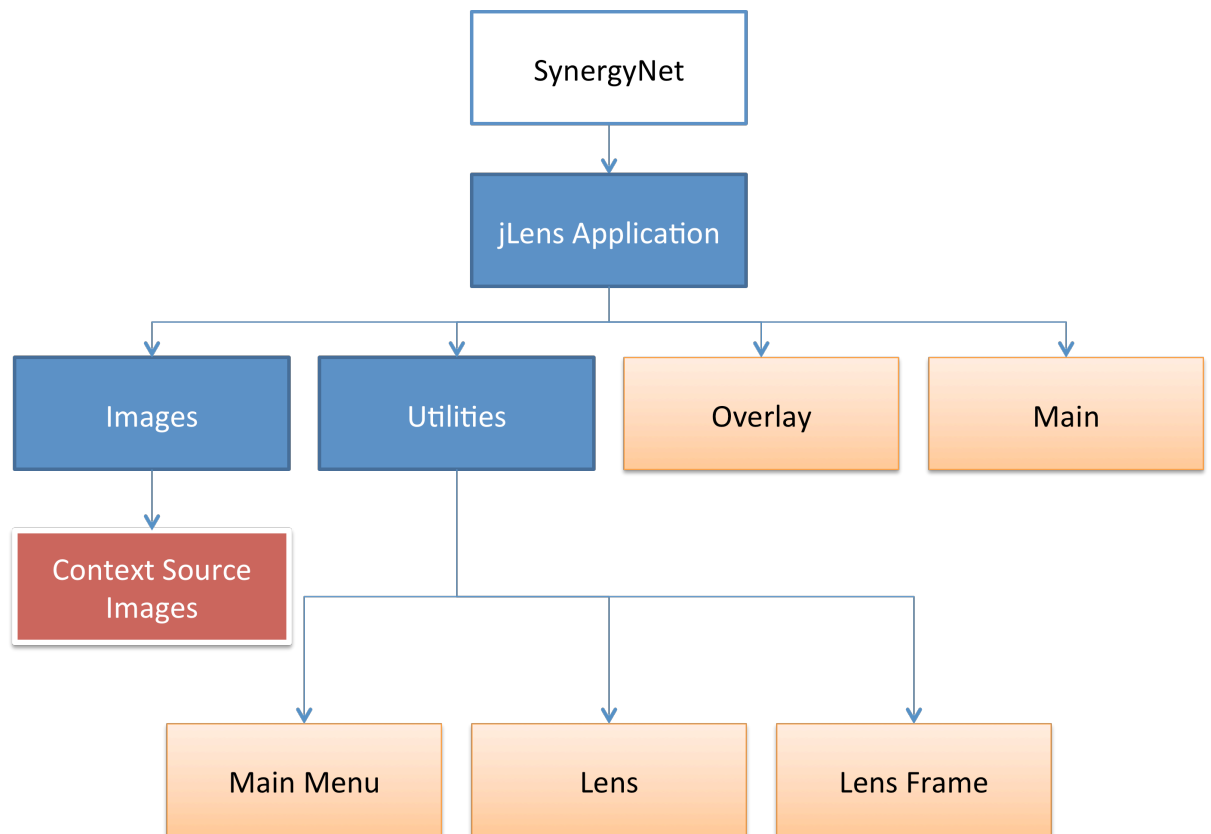


Figure 4.27 – Showing the component structure of the jLens application. Items in orange represent modules/classes. Items in blue represent folders and items in red are groups of images.

The components of the system are shown in (Figure 4.27). The items in blue are the folders used to separate the modules, the orange items represent the separate modules and the red item is the bank where the images are stored. The components are summarised as follows:

Classes

- **Main** – This is the main executable component that SynergyNet will run. From here the other components can be called. This will provide the majority of the low-level functionality such as adding the multi-touch overlay and obtaining system screen resolution. This also details how the application should look at start-up including main menu placement and background image loading. Other functionality in this component will include Z-ordering of elements, to ensure that image occlusion is managed and the lenses are positioned above the background image and not

underneath it, and various parameters to ensure a safe exit such as stopping several services.

- **Overlay (Corner Hot Spots)** – When the main menu is hidden the ability for it to be revealed should be built into the system. However the method to reveal the menu should not interfere with the usability of the system. This component will place two event listeners on both the top-left and bottom-right of the screen. When the user presses on these two points simultaneously the main menu will re-appear.
- **Main Menu** – This component details a main menu that will be present on the start of the application. From here the user will be able to load a lens onto the screen, change the main image and return to the SynergyNet main menu. As the menu will use up a proportion of the screen when it is present, it is important to be able to hide the menu when not needed.
- **Lens Frame** – The lens itself will be constructed of 2 components. The Lens Frame will detail how the lens will appear on the screen to the user. This will contain positioning information of the graphical interface elements and the functions to be carried out when the lens is closed as well as z-order information for the lenses. The user(s) will be able to create many lenses in the application.
- **Lens** – This component will describe how the lens operates and how the user can interact with it. It will contain the algorithms for zooming into the base image and locking the lens. It will also allow for moving the lens and passing it to another user. A function will be included that controls how the lens image changes when the zoom slider is moved up and down.

Folders

- **Images** – This directory will hold the images that the jLens system can interact with. More information about this section can be found in Section 5.1 – Technology Decisions.
- **Utilities** – This package will contain several components that constitute the creation of the on screen lens as well as the component that describes how

the main menu should be drawn and actions to be taken when the buttons on the main menu are pressed.

4.1.3 Design Patterns

As the system has been designed to work in many educational contexts, from biology to history, it is important that the creation of the system is done in a modular way. This will allow for future extensibility and maintainability. With this in mind, the viewing aspects (the lenses) must be kept separate from the underlying imaging system.

Traditionally a Model-View-Controller (MVC) system is used for graphical user interface design as it allows for multiple presentations of an object and separate styles of interaction with each of these presentations (Figure 4.28).

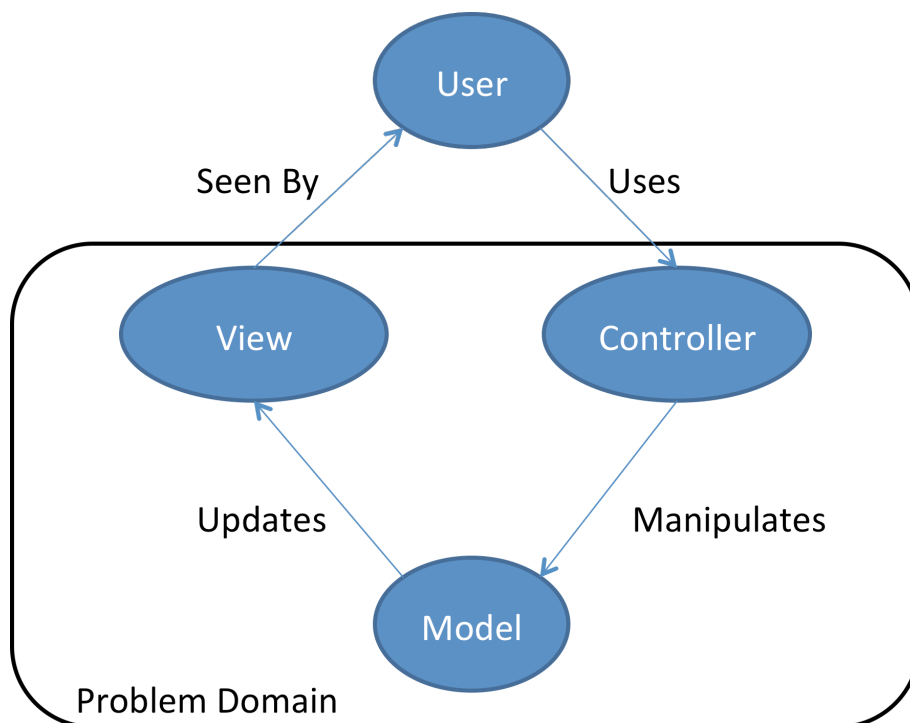


Figure 4.28 – The classic Model-View-Controller framework.

However the jLens system focuses on the View aspect of the MVC framework and when the user manipulates the lens the underlying model is not changed. This framework is insufficient for describing the system without some alteration.

The Observer pattern provides a greater fit for the aims of this application as it separates the display of the state of an object and allows for different displays to be provided. In this case the object is the underlying image and each lens acts as a different display. This model is display centric and therefore focuses on the View aspect of the MVC in a system where there is perhaps little change to the underlying object at run time.

4.2 Component Design

4.2.1 Images

The jLens application will be based around the idea that many users can interact with a single image regardless of the educational context. It is the underlying image that defines the applicability of the application in an educational environment.

Several considerations must be made when designing constraints for the images:

- The application will require at least 2 images (see section 4.2.3 – Context Sensitive Zooming for using more than 2 images); one that will form the static background image that the users can interact with, the second is the image that is displayed in the lens, that is related to the background image, but will be personal to each user and can be zoomed in and out of (Figure 4.29).
- All used images will need to have a maximum resolution defined that should not be exceeded due to potential performance issues forming. This defined resolution will be such that any further increase is of no benefit to the user because of the limitation in the maximum screen resolution.
- Both the static background image and the lens image will have a fixed resolution and aspect ratio for any image type. This will not need to be changed during the execution of the application
 - The static background image will be the same resolution as the screen it is being displayed on with a 1:1 pixel mapping. This will provide maximum readability with minimum system resource usage.

- The lens images will have the same aspect ratio as the background image and will have a scale factor larger or equal to that of the background image.

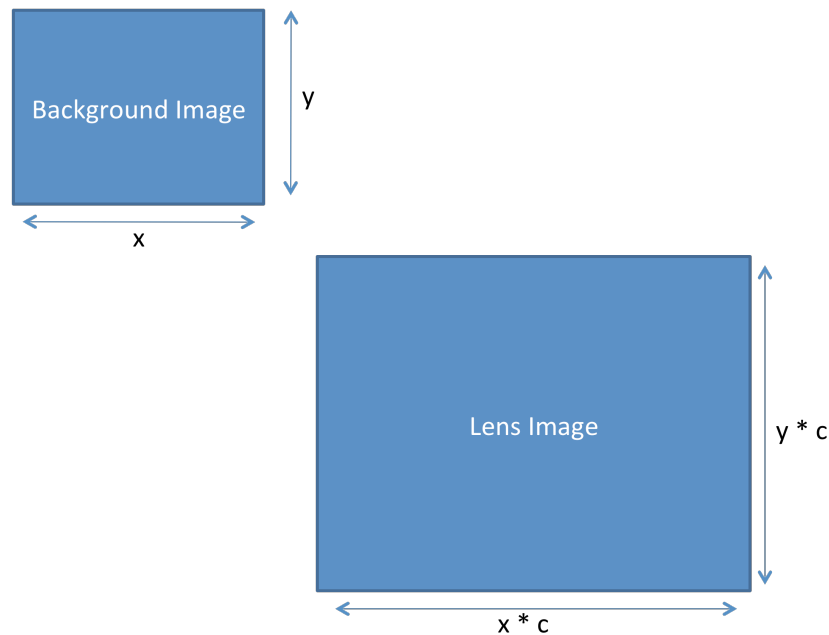


Figure 4.29 – Diagram showing the relationship between the lens image and the static background image. Where c is a constant to ensure the Lens Image maintains the aspect ratio of the background image.

4.2.2 Lens

Section 3.2.1 outlines the need for a unified interaction system that allows many users to engage collaboratively over a single image by being presented with their own interaction tool. The use of such a tool would prevent interpersonal friction and promote mutual engagement. To facilitate these ideas the notion of a lens is used within this thesis and the ability to collaborate over a single image that the lens will provide will meet Goal 1.

The lens element is the key aspect of this system as it provides each user with a portal to interact with the underlying image (Figure 4.30). In each application session many lenses can be created and the number of persistent lenses should only be limited by the available screen space with no noticeable performance

decrease to the users. However, Goal 2 states that the occlusion of the main background image created by the lens should be kept to a minimum as the image provides the key frame of reference for navigation around the system therefore the lens will be designed to ensure the buttons are easy to select but are small enough to prevent excess occlusion in order to meet Goal 2.

The lens itself will be formed of 4 basic elements with the ability to add more elements if required due to the modular design. The following list is visualised in Figure 4.30.

1. The main body of the lens will provide the user with a view of the underlying source image. This component will be the largest in the set of elements that make up the lens window. Using a single finger gesture the user can move the lens around the screen and also pass it across the table to another user. Using two or more fingers the user will be able to rotate the lens as well.
 - a. This element of the lens will also provide the user with another area to interact with. If a pop-up box appears in the lens window then the user can press buttons and move information around within the lens. Therefore the lens can be comparable to another screen
2. On the top right of the main lens window will be a red cross that the user can press to end the current lens session and close down the lens window.
3. Across to the right of the lens window will be a slider that the user can touch and slide up and down to zoom in and out of the source image. This slider will work on a percentage basis where 100 is the maximum extent of the zoom in. This method will allow the image displayed in the lens to be changed between different zoom levels. The slider model used here is based on the work in the DTLens project (Forlines, 2005) (see section 4.2.3 – Context Sensitive Zooming for more information).
4. On the bottom right of the lens window will be a padlock icon that toggles between locked and unlocked states when pressed by the user. When the lens is in the locked state the user can move the window and the image displayed in the lens will remain stationary the entire time the lens is

locked. This will allow the user to find an area of interest on the source image using the lens, lock it, and then pass the resulting area to another user for comparison and analysis.

- a. When the lens is locked and moved away from the area where the locking action took place an animated dotted red line will appear from the centre of the lens to the centre of the point of first locking. This will provide the users with a visual cue to show where the image in the lens originated. This is especially useful when the user has zoomed into the source image to an extent that the location of the image is undeterminable.

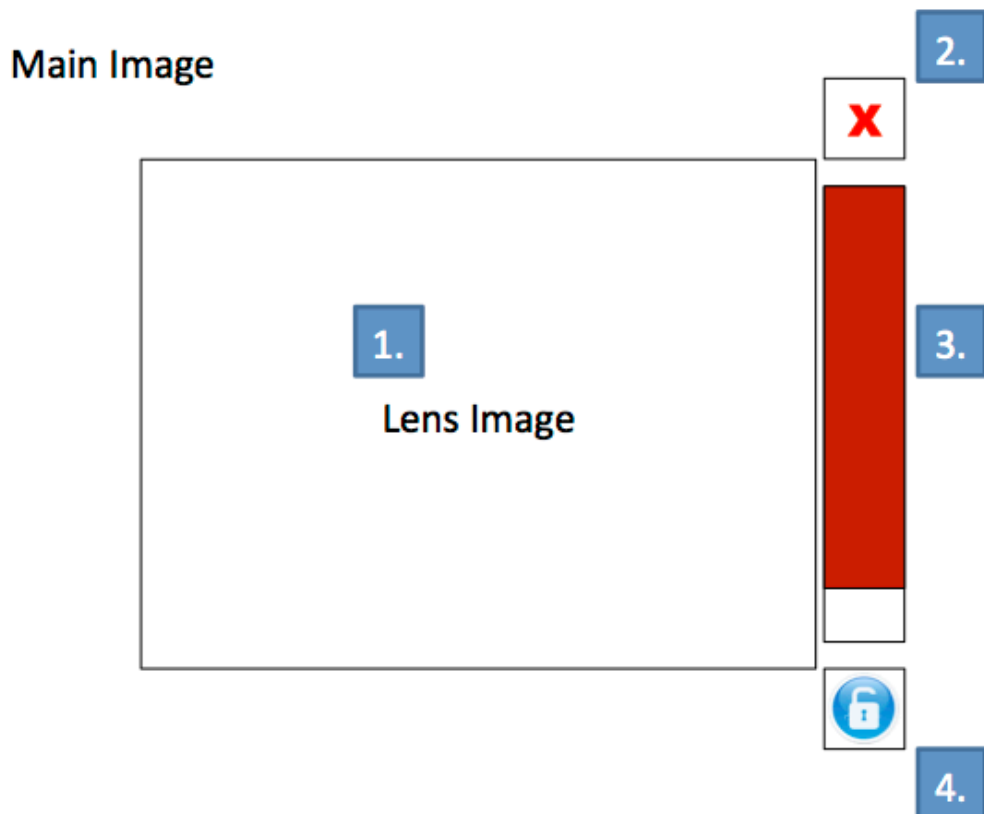


Figure 4.30 – Showing the lens element of the system with the close button, lock toggle and zoom slider.

When multiple lenses are present on the screen an issue of overlap becomes apparent. In this situation the z-ordering will be determined by a “last touch”

process. This is where the highest lens (the one on top of the stack) will be the one that has been pressed most recently.

4.2.2.1 Interaction design of the lens

The design of the lens element is based on the analogy of a magnifying glass. The user has a view of the underlying map of a fixed resolution that they can inspect without using a tool in a similar manner to a user inspecting a paper map. By employing the use of the lens a mental model is created that allows the user to interact with the lens as if it was a physical magnifying glass. The user can move the lens across the underlying map and can use it to zoom into the map in a similar way that an individual can use a magnifying glass to inspect an area of the underlying map that is not visible with the naked eye.

The mental map is altered slightly by the interaction techniques that the user can apply to the lens. In a similar analogy to the sheets of paper on a desk the lens can be assumed to have properties similar to paper so that the user can apply the same flicking motion to throw the lens across the table to other users with similar laws of deceleration on the lens as paper. The user can also use two or more fingers to rotate the lens and lenses can obscure each other if they overlap similar to the paper mental model.

4.2.3 Context Sensitive Zooming

Goal 3 states that the lens should have the ability to be zoomed into a point for precision selection without affecting the background image for the other users. This will allow the user to explore areas of a large resolution map with greater precision without disturbing the map for the other users. This combined with the locking and passing function of the lens allows for user to isolate an area of interest and pass the lens to another user to facilitate collaboration and therefore also meeting Goal 1.

The process of zooming in reveals more data that can be compared with the other users. This notion of zooming and revealing data can be expanded so that the image displayed in the lens window can change at different zoom points.

For example, in the case study of an historical application that presents the user with a large map of Europe during the Black Death the base image would be a standard map of Europe. From here the users can draw lenses and begin to zoom into areas of the map. In a traditional sense the act of applying a zoom factor would provide a standard magnification of the underlying image until more detail is shown (e.g. small roads and cities within a country). Context-sensitive zooming would replace this standard magnification data with rich content when the user reaches a certain zoom percentage over a specific area. This would focus the user to a particular area of interest and tailor the map to a certain educational subject. Using the Black Death example presented in section 3.2, a user could draw a lens and zoom into London and at a certain zoom level the image in the lens would change to an image or a video clip of the poor living conditions of that era instead of the standard magnification feature of zooming in.

One of the concerns with the ability to swap out images on zoom is memory usage. The resolution of the image viewed inside of the lens is a scale factor of the aspect ratio of the main background image. When a lens is first drawn on the screen the lens image will be defined and rendered before the user can take control. This rendering time will potentially require the user to wait a few moments depending on the file size of the image. This wait is acceptable at the launch of the application as the rest of the run-time will subsequently be smooth with little to no interruption to the user. However a problem arises when the user zooms into a level where the lens image will be swapped out as the original image has to be removed and the new image has to be loaded, resized, cropped and rendered with no discernable interruption to the user. Several methods for dealing with this problem include tiling, where the new lens image is split up into sub-sections and only those sections where the lens is positioned over will be drawn. As these tiles are smaller than the component image the render time is reduced.

Another type of rendering can be done using heuristics where an image can be preloaded in the background when the user approaches the preset image swap zoom value. The advantage with the form of image loading is that there is no interruption to the user while the image is being read into the application so when the preset zoom level has been reached the new image is displayed immediately.

The disadvantage is that the algorithm to determine which image is load becomes inaccurate when the user zooms in and out erratically and the point could be reached where a zoom level is reached but no image is available to display. In this case the user would have to wait for the image to be read in and rendered as before.

Guidelines will need to be identified to determine the maximum number of image changes to be allowed in an application. This is again related to performance as too many images will cause a noticeable interruption in the running of the application as the frequency in which new images are required to be rendered will increase.

A key issue with the creation of new images for use in the application is image size in respect to readability. Guidelines will need to be put in place to ensure that any new image created conforms to certain rules about readability. This is important in context-sensitive zooming as the users could get frustrated with the system if text boxes and images are different sizes at the one zoom level.

4.2.3.1 Interaction design of context sensitive zooming

The key mental map that is created for the user after a cognitive walkthrough is the analogy that context sensitive zooming is similar to a microscope or a magnifying glass.

4.3 Component Placement

The placement of components needs careful attention if the aims of Goal 2 are to be met and occlusion is to be kept to a minimum.

Components in Synergynet are created using elements from the built in ContentSystem package. These component classes are simple elements that can be used to make a larger functional unit. Some of the elements include slider bars, frames, buttons and labels. All of these items have built-in methods for interaction via multi-touch and the developer can define some extended functionality such as event listening on button presses.

One of the difficulties faced when creating an object from various elements is the effect on the object when subjected to multi-touch interactions such as scaling and rotating. In traditional GUI creation systems such as Java's Swing (Oracle, 2010)

items can be nested so that when the user drags them using the mouse, the items remain in their relative positions. However with Synergynet (and other multi-touch systems) items can also be rotated and scaled but nested items take the event listeners from their parent elements making it difficult to adjust which areas of a particular item work independently of others. This means that if a frame is programmed to be movable using a touch-and-drag gesture and a slider is placed within the frame, the slider will move across the screen when dragged even though the function of the slider is to allow selection of a range of values without moving the frame.

In this research the problem manifested itself when the zoom slider was introduced to the lens item. When the slider was added to the parent frame, the events fired from dragging the slider up and down to select values were lost and instead dragging the slider moved the whole lens.

The first solution for this problem was to remove the slider from the parent frame and create a super node that contained both the frame and lens at the same hierarchical level. This brought back functionality to the zoom slider but another problem appeared on rotating the lens. When the lens was rotated by the user the frame and slider rotated about their individual axes not as one item. More specifically, the centre of rotation of the zoom slider was not the centre of the lens but the centre of the zoom slider itself.

The solution to this problem came after removing all the hierarchical attachments to every element and rebuilding the lens based on a controlled structure of inherited events and nesting. The final lens nest design (Figure 4.31) allowed for direct interaction with the individual elements inhibiting translation and rotation when these select elements were interacted with but on rotation and scaling of the whole lens, the elements retained their positions relative to the centre of the lens.

The main lens feature used in this research is constructed by a series of nested frames each containing separate functional elements. All of these frames are nested in one parent frame called *all*. Within this frame are two subframes: *window* and *zoomWindow*. *window* contains the *portal* and the *closeButton* and *lensLockButton* and these items can be touched and dragged to move the whole

lens around the screen. The *zoomWindow* frame contains the *zoomSlider* that will zoom the portal view in and out when touched and dragged. Dragging the *zoomSlider* will not move the whole lens. This hierarchical nest set up allows for the relative positions of the items to be maintained on rotation.

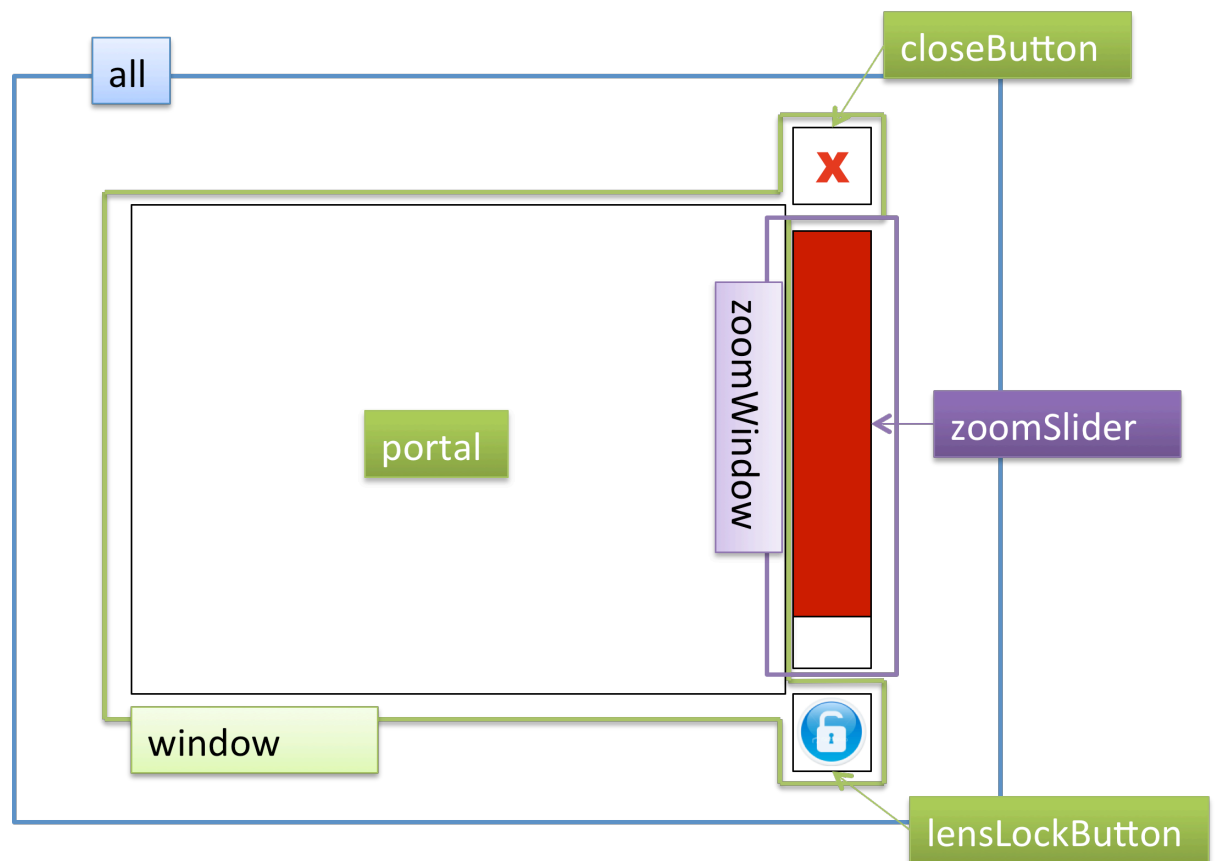


Figure 4.31 – Lens construction diagram showing the nesting structure.

The design of the lens system above gives the user full functionality to lock the lens, zoom into the lens with the slider bar and to rotate and move the lens but presents the user with a minimal interface to prevent occlusion and to meet Goal 2. The use of gestures to rotate and move the lens negates the need for extra buttons. The slider bar combines a means of visualising the level of zoom as well as providing an interface to alter the zoom level again minimising the need for extra buttons but maintaining functionality.

4.4 Accessibility and Usability Considerations

Due to the visual nature of the system and its potential use by users with limited technological knowledge some accessibility concerns are present. Firstly the

buttons and interaction elements need to be large enough to be pressed with a fingertip, although the concern with this is that if the elements are too large they may obscure other parts of the application and restrict usability and therefore not meet Goal 2. If users have digits larger than the buttons interaction may become difficult.

Another concern is the number of elements on the screen at any one time. An ideal maximum number of lenses to be present on the screen at any one time is 6. At the current standard resolution for multi-touch, 1024 x 768, any more than 6 lenses will result in excessive overlap or occlusion. The multi-touch tables in the Technology Enhanced Learning group at Durham University can comfortably seat 5 people around so a 6 lens maximum provides a good ratio between lack of occlusion and usable lens space.

The ability for each lens to be zoomed in or out individually means those users with sight difficulties can increase the size of the lens image to a comfortable level without affecting the workspace of the other users. This allows many users to work together without accessibility barriers.

4.5 Integrated Development Environment and Programming Language

This system will be programmed in the Java programming language (Java, 2010) using the Eclipse Integrated Development Environment (IDE) (Eclipse, 2010).

Java provides many features that make it suitable for a rapid prototyping system such as this one. Firstly it allows automated memory management and garbage collection to allow the coder to concentrate on content and not the allocation and reallocation of memory to prevent memory leaks. This feature is even more beneficial to a highly graphical system such as this one as the memory usage is optimised to prevent noticeable slow down to the user. As system resources could be potentially stretched, due to the multi-media nature of the system and the cross platform nature of SynergyNet, these automated features are useful.

4.6 The Iterative Development Process

The iterative development took place in several stages with each stage checked against the initial requirements to ensure that the objectives were being reviewed and met at each stage.

The starting point came from a pencil and paper session with TimeMaps where we discussed the core interaction process of using the existing single-user, single-touch system. The initial discussion was how to move away from the mouse and keyboard approach but still provide the precision of interaction. From studying the existing research and combining this with the fundamental usage of a standard desk it was decided to design the interface with the notion of a wooden desk in mind where paper can be stacked and thrown from one side to the other. This would provide a fluid interaction process allowing for users with any technological background to be able to understand how to use the system without concentrating on input methods. Feedback at this stage was provided by TimeMaps who agreed this was a positive means of interaction. The next stage was to define how to separate information for the separate users from the single background image.

The notion of a lens was created after observing the process of scrolling into a large image to reveal more detail only to discover that the field of view has decreased and the majority of the image has been pushed off the screen to the sides. Another paper and pencil session was used to understand how to combine the wooden desk notion with the enlarging image without obscuring the view for others. It was decided then to employ the lens system with it's own set of controls for each instance so that the image could be enlarged within the confines of the lens but it could also be locked to allow the passing to others. The first paper design allowed the user to move the lens with one finger and scale the image with two (**Figure 4.32**).

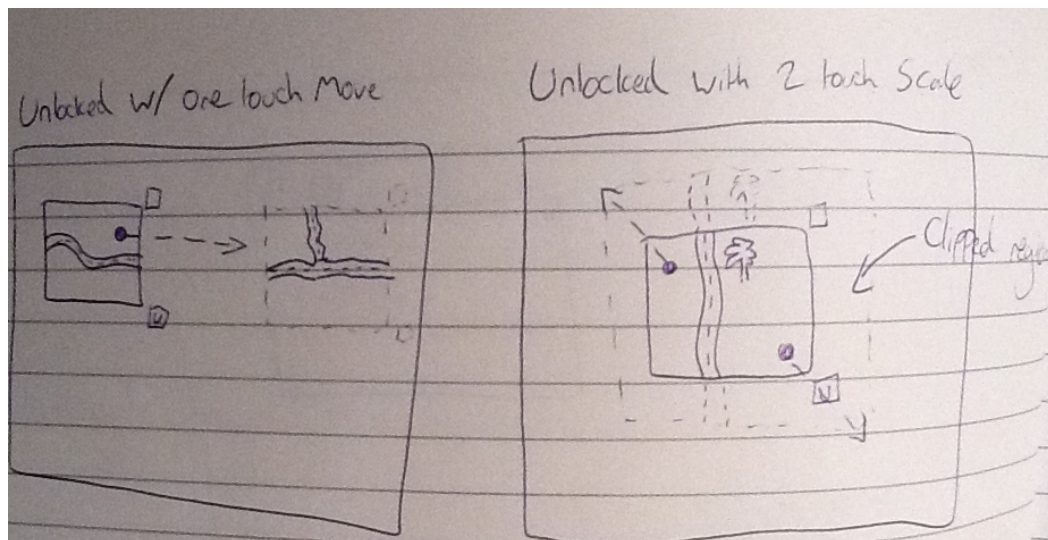


Figure 4.32 - Concept sketch of lens moving and zooming.

After feedback from members of the research group and TimeMaps an issue was discovered relating to the use of one or two fingers for moving and zooming as there was no scope for rotating the lens, an important piece of functionality for orienting the passed image to a user on the opposite side of the table. This feedback lead to the sketching, and final implementation, of the zoom slider where one finger could move the whole lens and two could rotate the lens window (**Figure 4.33**).

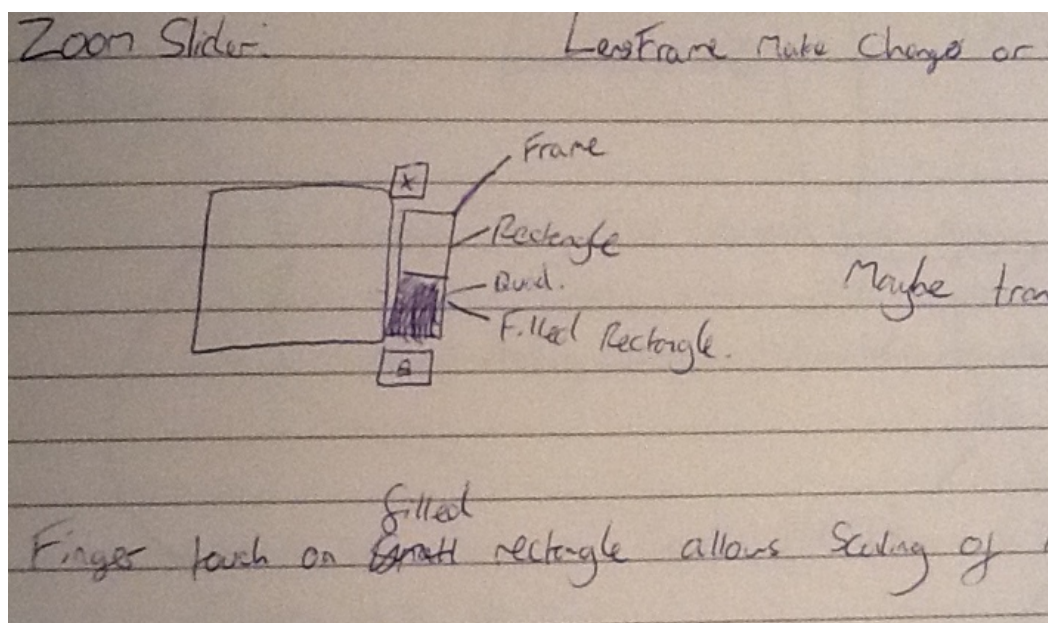


Figure 4.33 - Sketch of the initial zoom slider.

4.7 Fulfilment of Requirements and Summary

The design specified above fulfilled the requirements and objectives essential for this thesis and the end result was a modular, extensible framework that is highly adaptable for different subject needs. Each of the elements discussed in the design section attempted to meet the 4 Goals defined in Chapter 3. The lens system allows multi-user collaboration and the ability to zoom into a point while minimising the occlusion of the background map meeting Goals 1, 2 and 3. Regular meetings with TimeMaps ensured that the learning outcomes were maintained after the conversion and therefore Goal 4 was met. The implementation followed the design so that the Goals could be realised in a working system.

The implementation of the system followed good software engineering principles such as code reuse and low overall coupling between modules. Documentation was also produced for easy maintenance and future extensibility.

The system was created with an abstraction such that any image could be loaded into the system as the main background image or as any number of context-zoom images. This allowed a degree of flexibility when using the application for different subject purposes.

5. Implementation

The following chapter will describe the various choices, reasons and issues with the implementation of the design. This section will give details on implementation problems and any changes made to the design.

5.1 Technology Decisions

The technology choices for this research must allow for the rapid prototyping of an application and for regular testing to be carried out ensure that all of the goals have been met successfully.

5.1.1 Multi-touch Hardware

The final system will run on multi-touch hardware that converts finger presses into input gestures. This physical process provides the basis for interacting collaboratively as many users can gather and interact around a single table. This process provides the base for Goal 1 (Allow multiple users to collaborate over a single static image without altering the image for the other users). The physical layer of finger touch conversion is abstracted away from the developer via a hardware Infrared camera layer and the Synergynet framework.

For the purposes of this thesis, the application will be designed and tested on a PC running Windows XP with occasional releases being tested on either a Lumin (Evoluce.com) podium multi-touch table or custom designed tables.

5.1.2 Synergynet

Durham University's Synergynet system allows the developer to concentrate on designing and implementing the content of a system instead of worrying about the many combinations of multi-touch hardware over many system configurations or the process of converting the finger touch into a digital multi-touch input. The interpretation side of Synergynet is based on receiving TUIO (Bovermann, 2005) messages from the "multi-touch server" daemon application.

The listener built into Synergynet converts the raw TUIO data and converts it into touch events that can have actions assigned to them. The advantage of this method is that a multi-touch application can be designed for any system/table type (multi-touch or not) by sending TUIO data to the Synergynet framework. The immediate advantage of this is that the software created can be run on any multi-touch hardware. For a developer it means that Synergynet and any created applications can be run on a standard PC with a mouse, keyboard and a monitor in Simulator mode. In this mode the user can click with the primary mouse button to simulate a finger touch on the screen. By pressing the secondary mouse button a touch can also be simulated, but by holding the secondary mouse button and moving it to another location on the screen a two-fingered touch can be simulated. In this mode when the mouse is moved the two finger touches maintain their relative orientation but the user can press and hold CTRL and then move the mouse to move the two touches closer and further apart to simulate scaling. Additionally, the user can press and hold shift and move the mouse to rotate the touches around the centre point to simulate standard rotation.

The advantage of this setup is that a developer can create and test a multi-touch system using a standard PC and control the application with simple multi-touch gestures. An application designed using the simulator will be easily transferrable to a multi-touch table with little or no changes being necessary.

Another feature that Synergynet provides that is useful for this system is application launching. Synergynet includes a main menu loader that shows all the available applications that can be executed (Figure 5.34). This allows applications to be developed without worrying about separate execution parameters.

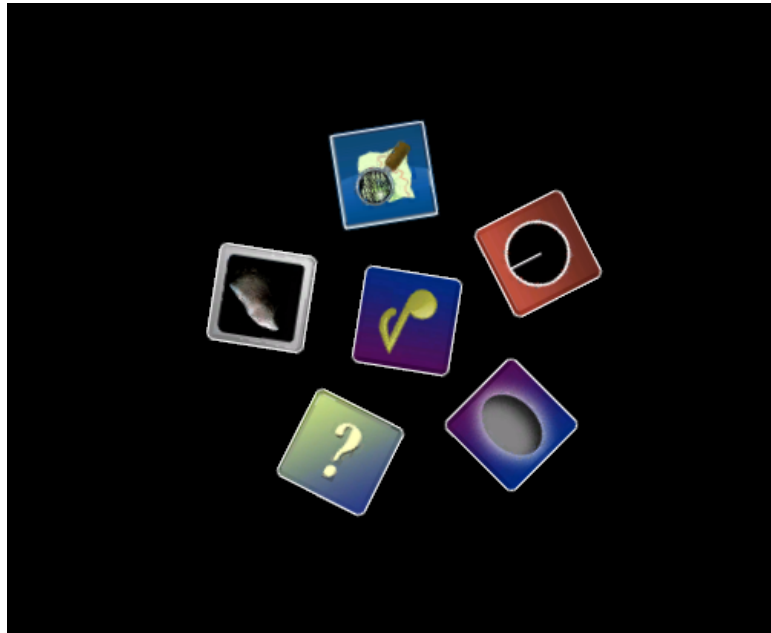


Figure 5.34 – The Synergynet main menu for application launching.

Every application is stored as a package within the `src_synergynet.synergynet.table.apps` package within the Synergynet framework. The framework defines that within the root of the application package a .png image can be stored that acts as the application icon for the main menu. This is automatically read into the system on launch via an XML file.

This is another requirement of the Synergynet framework and every application package must hold an XML file containing some data about the execution parameters of the application. Some of this data includes basic information such as: the name of the application, the author's name and the version number. Important runtime information is held in the "clientcomponent" tag including the class to execute within the application's package and the path location of the icon to display on the main menu.

This XML file is all that is needed to integrate an application into the Synergynet framework and the short length of the required file is an advantage as less time can be spent worrying about the execution details and instead spent on implementing the application.

5.1.3 Java

This system will be implemented using version 1.6 of the Java programming language. The Synergynet framework had also been programmed using Java. Java is a suitable choice for this system as it allows cross-platform applications to be created without the need to recompile or use different operating system dependent libraries. As multi-touch is a hardware technology that interacts with a software control layer it can be implemented on a number of different platforms. Many modern operating systems now contain native support for multi-touch so a cross-platform programming language is a suitable choice.

This research will see the creation of a piece of software that will be changed and retested on a regular occasion as requirements change. Using Java is an advantage for this type of rapid prototyping system as it allows for automatic memory management and garbage collection whereas in other syntactically similar languages, such as C++, the developer must spend time ensuring that there are no memory leaks. In this case it means that more effort can be placed in creating the content for the system as some of the background work is completed automatically.

Java is also an object-oriented language, which allows the implementation to easily follow the drawn-out design. This is a benefit as the design can be created in a modular format with separate functional sets and these sets can produce some functionality individually as well as when combined to make a whole program. This feature of Java allows for code-reuse to reduce the amount of time spent altering similar code fragments. Another advantage of code-reuse is the possibility of transcription errors is greatly reduced.

As Synergynet is a large framework the idea of object orientation allows a developer to create applications easily in a modular way and then insert them into the framework much like building blocks.

Part of the Synergynet project allows the creation of distributed applications so that the interactions on one multi-touch table can affect the results of another. This allows for multi-user collaboration over multiple tables. Java allows for this as it has

network integration built into it allowing for the easy high-level creation of distributed programs.

It can be argued that Java is a slower and more memory-consuming language than natively compiled languages such as C++. However for this research, the limiting factor in terms of speed will be the number of lens windows created and the speed at which the end users can rotate and pass the lenses across the screen. The speed benefits of C++ versus Java can only be seen when executing algorithms consisting of thousands of lines of code. For this thesis the benefits of using Java outweigh the negatives.

5.1.4 Eclipse

It has been decided that the development environment in which this application will be created will be the Eclipse IDE (Eclipse, 2010).

Eclipse provides many benefits for this research from simple features such as an in-depth code editor, debugger and the ability to hot-code an application.

Importantly for this research, Synergynet is hosted on Google Code (code.google.com) and can be accessed using a version control plug-in. Eclipse supports many different types but for this research Subversion will be used and more specifically the Subclipse SVN plugin will be used. This allows for the Synergynet repository to be specified in Eclipse and for the latest trunk of the framework to be downloaded. When updates are made to the trunk of the Synergynet code, the latest changes can be downloaded automatically.

The Eclipse IDE also allows for changes in the execution parameters, the most useful for this research being the ability to increase the size of the dynamic memory allocation of the Java virtual machine. This is described in more detail in the Implementation Issues section.

Eclipse also allows for the editing of different languages. In this research both Java and XML will be used so the ability to edit both with highlighted syntax and error reporting is an advantage.

5.1.5 Adobe Photoshop

The central focus of this application is to allow interaction with large-scale images such as maps or satellite photographs. The background image provides the key reference point for navigating the system and this aspect is described in section 3.2.2 as occlusion of this image can impede the ease of use of the system. As described in the Design in Section 4, the application must also allow for context-sensitive zooming to meet Goal 3 (Allow the lens to be zoomed into a point for precision selection without affecting the background image). These processes require a large amount of image processing, creation and manipulation with images of very large resolution. This requires robust software that runs smoothly and allows the editing of large image with reduced slowdown in performance or crashing. The decision was made to use Adobe Photoshop CS5.

Photoshop has many features that are useful for this research including compression functions to greatly reduce the file size of an image without compromising on the image quality. This feature alone is vital for this research as images need to be loaded and replaced in memory quickly so that the user does not experience slow-down that would remove the immersion factor of the final application. Along with this, the images must retain a high enough visual quality so that the users can zoom into the image at great lengths and still be able to read and understand the visual data without the presence of visual artifacts or distorted colouring.

For the purposes of the experiment and demonstration of the system the existing applications created by TimeMaps will be edited and more specifically the maps used within these applications will be extracted and edited to fit within the requirements of this thesis. Currently the TimeMaps maps contain icons and other information that need to be removed before they can be inserted into this system. The content-aware delete function of Photoshop CS5 is useful for removing these features quickly which helps with the creation of a rapid prototype. The content-aware delete algorithm examines the surrounding area of the selected area for deletion and replaces the deleted section with a continuous flow of the surrounding parts. This is suitable for a simple image such as a map because the

colours and shading are simple and the contours of the edge of countries can be followed behind a deleted section successfully.

As described in the Design section the system will exhibit context-sensitive zoom. One of the challenges of achieving a smooth transition when zooming into an image and having the image replaced at a certain zoom level is to ensure that the replacement image follows the same relative dimensions of the replaced image. Photoshop contains several tools to aid this including a ruler that surrounds the boundary of the image as well as a click-and-drag pixel measurement.

5.2 Implementation Issues

This section outlines the strategy adopted to implement the system as well as several challenges that occurred during the implementation stage.

The implementation strategy consisted of creating a workspace that copied the component design in **Figure 4.27** and that ensured each separate module could run independently of the overall system. The testing was continuous throughout the implementation process as the system was prototyped.

5.2.1 Power of 2 Textures

Synergynet is a framework that renders content items using the JMonkeyEngine (JME) (jMonkeyEngine.com, 2010) which is a scenegraph-based architecture that uses an implementation of OpenGL for Java.

Due to the multi-touch nature of Synergynet all items are rendered on Open GL Quads wrapped in the image as a texture. Textures used in games and other 3D environments are traditionally created with resolutions of powers of 2 and are tiled to ease processing and memory allocation on graphics cards. This has lead to many old graphics chipsets only supporting texture resolutions in the range of powers of 2. As applications created using Synergynet require images of many different resolutions and colour depths to be drawn and displayed a more modern graphics card is required.

This problem was fixed by the installation of graphics card containing a chipset allowing the rendering on non-power of 2 textures.

5.2.2 Memory Limitations of the Java VM

One issue that was very quickly discovered was the effect of loading an image into a Synergynet frame that was larger than a certain size. This was discovered upon loading in a topographic image that was over 1.7 MB in size and had a resolution of 3040 x 3168 pixels and any subsequent image that was larger than these parameters would cause the application to end.

On investigation this was due to either the application having a memory leak, an option that was discounted after running the application for an hour with a smaller image and monitoring the system memory usage, or the exhaustion of the Java memory heap space.

By default Java allocates 128 MB of memory for heap space usage and although the image is only 1.8 MB in size the process of reading this into the application and displaying it uses considerably more quantities of memory.

To fix the problem the allocated JVM heap space needs to be increased to 512MB.

5.2.4 Non-Central Zooming

The Frame content item within Synergynet allows for an image to be drawn within it using the drawImage method. This method has the following parameters:

```
Frame.drawImage(URL imageResource, int x, int y, int  
                width, int height);
```

The imageResource parameter is the location of the image on the system and this application uses the class.getResource method to obtain the image from the workspace directory. The remaining parameters specify the X and Y locations that the top-left of the selected image should be drawn and the width and height that the image should be extended by.

The portal Frame works by selecting a section of the image to draw and clipping the rest of it therefore by selecting an X, Y top-left value of 0 and small width, height values the appearance is given of a zoomed out image starting from the absolute top-left of the original image. In contrast, by selecting the same X, Y values but increasing the width and height the impression can be given that the image has

been zoomed in. It is the combination of this system and a percentage received from the zoom slider that provides the visual impression of fluid zooming in and out of a base image.

This example can be expanded for when the lens is positioned in the centre of the screen. When the image is now drawn the X, Y top-left values will be negative as the top-left of the base image will be further up and outside of the visible frame area. The width and height will remain the same as this is dictated by solely by zoom level and not lens translation.

The illusion of zooming appears when the user touches the red zoom slider and moves their finger up to zoom in and down to zoom back out. The zoom slider has a total zoom of between 15% and 100% zoom where (due to the fixed image size) at the 15% stage the image in the lens is the same scale and resolution as the main image. 15% is used as the image is still displayed on screen at a 1:1 ratio with the main image, if this restriction were not in place then the image in the lens would zoom out past the scale of the main image causing an unwanted effect. At each movement of the user's finger an event is fired that takes the current percentage of the slider and multiplies it by the actual resolution of the main image. This redraws the lens image on every finger movement giving the impression of zooming into the main image.

A resolved problem occurred due to the drawImage method only taking parameters that specified the top-left of an image. As the user zoomed into an image, the centre of zoom became the top left of the lens and not the centre of the lens as desired. This issue affected the ease of the system and provided a difficulty in operation. The image in the lens could not be zoomed precisely into a point and collaboration was affected which presented a potential failure of meeting Goals 3 (Allow the lens to be zoomed into a point for precision selection without affecting the background image) and 1 (Allow multiple users to collaborate over a single static image without altering the image for the other users) respectively.

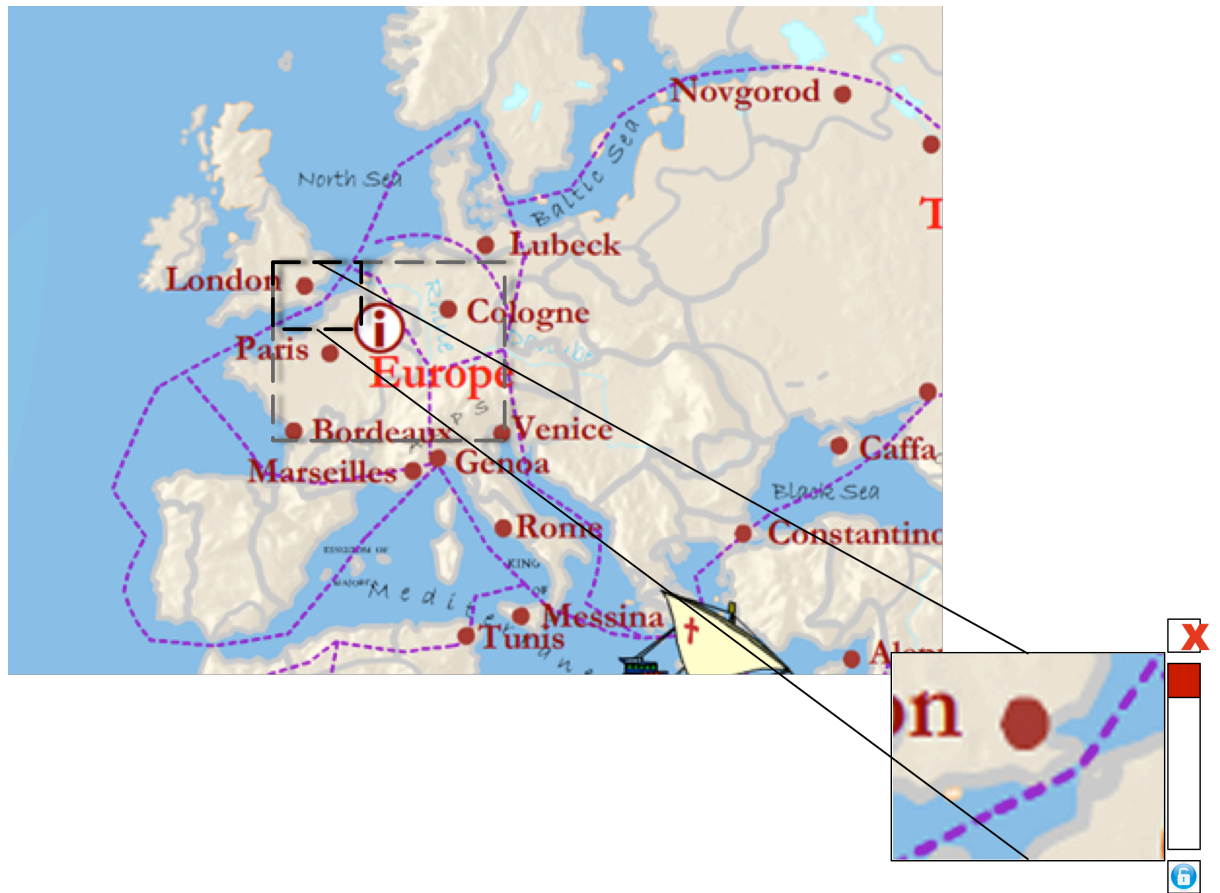


Figure 5.35 – Showing the area of zoom on a lens with the top-left bias. The grey dashed box shows the view of the lens in zoomed out mode and the black dashed box shows the complete zoomed in view of the lens.

The problem was resolved by altering the act of the zoom slider on the drawImage method. More specifically, by applying the zoom slider percentage function to the X, Y top-left parameters. The idea was to move the top-left of the image further away from the centre, towards the top-left of the screen, by a certain factor so that at full zoom in the top-left and bottom-right of the original image were equidistant from the centre of the lens.

This was managed by creating a modified percentage called `rectifiedCurrentPercentage` that takes the value of the `zoomSlider` percentage and subtracts 15%. This conversion is important because for a smooth zoom into the centre of the image the percentage scale needs to run from 0% on zoom out to 85% on zoom in. If the percentage were unchanged the zoom would not focus in on the

centre of the image but instead sweep from one side of the image to the other over the course of the zoom.

With the rectifiedCurrentPercentage the following function was created for the X, Y top-left parameter for the drawImage method:

$$\begin{aligned} &\text{Current Slider Percentage} * (\text{Screen Pixel Width} / 0.15) - \\ &\text{rectifiedCurrentPercentage} * (\text{Screen Pixel Width} * 2) \end{aligned}$$

The same function is used for the Y value as well; however the Screen Pixel Height is measured instead in this instance.

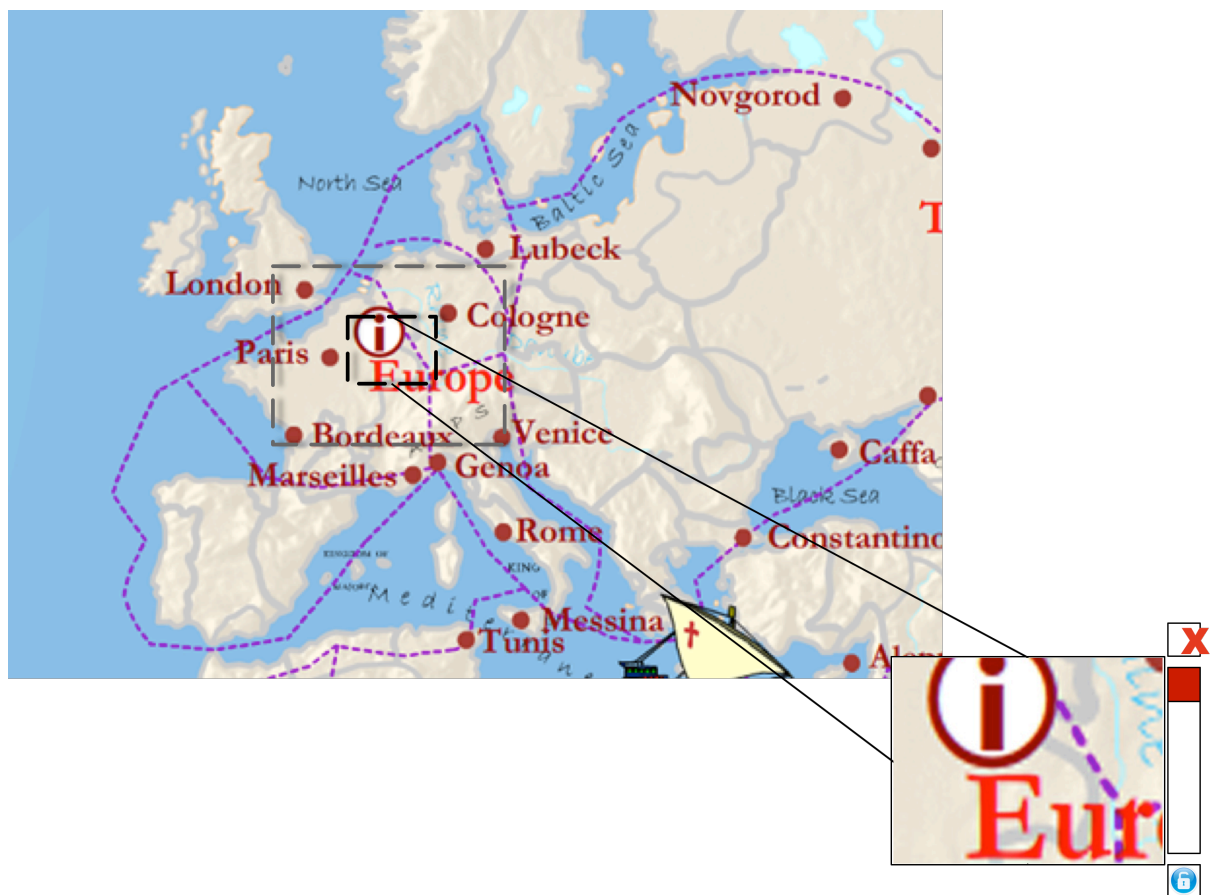


Figure 5.36 – Diagram showing the refactored algorithm enabling the lens to zoom to the direct centre of the image and not the top-left.

The addition of a scaling factor to the X, Y top-left parameter allows for the smooth zoom into the centre of the image (Figure 5.36).

5.2.5 Locating the Origins of Multiple Lenses

A problem that was faced when a lens is drawn on the screen and then locked is trying to identify where the locked image in the lens has originated. This is not a problem for one user working with one lens as the user knows where the lens was created. However, if there are many users creating many lenses and then passing them around a multi-touch table the origination aspect can become confusing. If a user loses the originating location of a lens then Goal 1 (Allow multiple users to collaborate over a single static image without altering the image for the other users) is affected as collaboration becomes difficult if the users cannot identify where the area of interest in the lens is based on the background map.

A solution was created that involved drawing an animated line between the centre of the lens to the point that the lens was first locked on the screen. This would allow many frames to be locked and moved around the screen but the origin of the image in the lens could always be determined (Figure 5.37). The line itself is 1 pixel thick to prevent unnecessary occlusion in order to meet Goal 2 (Minimise the occlusion caused from an interaction tool but maximise the usability of the interaction tool.).



Figure 5.37 – Diagram showing the connecting lines between the locked lenses and origination point.

5.3 Software Engineering Practices

The use of good software engineering practices was vital to the success of the research. The framework nature of Synergynet and the open structure of jLens meant that reusable components and keeping modularity was important to allow the system to be tailored to other purposes in the future and for ensuring maintenance was always possible.

5.4 Summary

The decision to use Synergynet and Java as a development language and framework was beneficial in a number of ways. Firstly the object oriented feature of Java and Synergynet allowed for easy access to the hardware events of the multitouch tables-an especially useful feature due to the two different models of multitouch tables used in this thesis. One version of Synergynet could be deployed on different hardware and the applications would work seamlessly across them by

abstracting the hardware calls to the touch sensors. The object orientation also allowed for the easy conversion from the design of the system, with the various functional units, to the final implementation. The ease of hot swapping and changing code fragments also allowed for quick debugging and the resolution of the implementation issues described in section 5.2.

The use of .xml files in Synergynet for configuration allowed for the quick change of settings without resorting to complex code changes, providing another benefit for prototyping.

6. Evaluation

The evaluation chapter will discuss how the final product was assessed to ensure it met the required goals for this thesis.

6.1 Experimental Approach

An experiment was set-up to evaluate if each of the four goals defined in section 3.2 had been met and therefore if the research question had been answered successfully.

The evaluation took place over 4 days and was based around the converted TimeMaps application running on one multi-touch table in the Technology Enhanced Learning (TEL) department at Durham University.

The evaluation consisted of 20 participants split equally into two groups; the first being industry professionals with previous experience of using multi-touch systems. These participants included two members from TimeMaps, an audio producer, some multi-touch hardware designers and other professionals within the field of multi-touch including staff representing local education authorities. The second group of participants consisted of users who had little or no prior experience with multi-touch systems. The experiment was setup with a single map of Europe with several interaction points scattered throughout containing information about the spread of the Bubonic Plague. Mirroring the Black Death content of an existing single-touch TimeMaps application.

The number of users varied between each session between 2 and 4 per table with only 1 table active in the room for the experiment. The 2-4 participants in each session were related by background. For example, the researchers all took part in a session together and the local education authority participants took part in a session together. This allowed for the communication and collaboration between users but the results maintained reliability by keeping user groups together in each experiment.

As the system is aimed at the education sector the selected participants would provide valuable feedback based on their experience in their particular fields. As the software is scalable the end users may be from either primary or secondary schools and therefore the representatives from the local education authorities would provide useful feedback from these sectors.

A questionnaire was designed and produced that presented the participants with 6 questions encouraging them to interact with the system and provide feedback on the various questions. Each of the questions was designed to cross-reference the goals outlined in section 3.2 and were split into 2 parts; A Likert (Dawes, 2008) scale and a comments area. The Likert scale was used because it allowed the participants to answer the questions using a set number of answers on a sliding scale. This was an advantage when the results were analysed as both positive and negative responses could be identified immediately and the comments area allowed the participants to explore their own responses in more detail.

An example questionnaire can be seen in Appendix – Sample Questionnaire.

At the start of the experiment each user was given a brief on the research behind the system and why it was developed. The brief contained information about TimeMaps and a detailed summary about the products they create and the issues of the original single-user, single-touch applications. The interaction methods of the existing TimeMaps software were explained to the participants so that they could compare aspects of the converted system with the original system. The participants were allowed to explore an existing single-touch TimeMaps application, which also followed the spread of the Black Death, on a separate machine with a keyboard and mouse before being allowed into the room with the multi-touch table presenting JLens.

During the experiment the participants were encouraged to explore the system in their own time and discover the various functionalities. This was aided by the brief given at start of the experiment and the structure of the questionnaire directed the participants through the workflow of the system.

The participants were encouraged to fill in the questionnaire at any stage of the experiment so that they could concentrate on using the system. During the

interaction stages of the experiment their interaction techniques were observed to identify the positive areas and problem areas of using the system. The observations were carried out during the whole experiment and a record was made when a participant had trouble interacting with an item of functionality or made a comment relating to a potential future direction or study for JLens. These observations were recorded by the principle investigator and were collated into Observational Results.

6.1.1 Techniques Considered

Other techniques were considered for the evaluation including structured and unstructured interviews as well as a hall-intercept test where a selection of random employees from different business units in TimeMaps would have been selected to take part in a trial. The interviews would have provided more detailed analysis of the system but time was a limiting factor as the evaluators were present for only a short while and therefore a wider coverage was more important.

The use of a hall-intercept test would have been useful as it would have allowed members from TimeMaps, the main stakeholders, to test the system. It was decided that the best course of action would be to use other, indirect stakeholders to help evaluate the system to provide their individual domain experience. Additionally, two members of TimeMaps were present for the evaluation.

6.1.2 The Questions and the Goal Relevance

This section will state the questions asked during the experiment and how each question relates back to the goals of this research. The questions were placed on the questionnaire in order of increasing complexity of the interaction with the system. For example, basic interaction techniques such as moving the lens were tested before more complex interactions such as zooming. This means that the ordering in terms of goals was not in order with the questions.

1. How would you rate the ease of use of moving and rotating the lens?

Question 1 relates to Goal 2: Minimise the occlusion caused from an interaction tool but maximise the usability of the interaction tool. This question prompts the

user to begin to explore the system and how to interact with it. This question invites the user to detail the usability of the lens system.

2. How would you rate the ease of use of zooming the lens into a point?

This question relates to Goal 3: Allow the lens to be zoomed into a point for precision selection without affecting the background image. The second question asks the user to evaluate a more complex interaction task of being able to locate a point of interest on the background map and zoom into it to show precision selection. This more involved procedure provides data to evaluate if the system meets goal 3.

3. How would you rate the ease of use of locking the lens and passing the lens to another user?

The third question cross-references both Goal 1: Allow multiple users to collaborate over a single static image without altering the image for the other users; and Goal 2: Minimise the occlusion caused from an interaction tool but maximise the usability of the interaction tool. This question is relevant when two or more participants interact with the table simultaneously and lock the lens onto an area of interest and pass the lens to another user simulating a pupil sharing information with another pupil. This aspect provides data to evaluate if the system meets goal 1. Goal 2 is met by asking the participants how the ease of use of navigating changes when many lenses are on the screen at once.

4. To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application?

This particular question asks the participant if the historical map application is a suitable application type for conversion. This takes into account the multi-user aspects that have been added and the application's basis around a static map.

Question 4 cross-references Goal 1: Allow multiple users to collaborate over a single static image without altering the image for the other users.

5. To what extent do you agree/disagree that the ability to context-zoom into a point to reveal information aids with the flow of the system (when compared to the traditional pop-up window)?

Before this question is answered the researcher describes to the users, from the brief, how the existing TimeMaps applications work and how the information points are traditionally interacted with. From this they can make a comparison of how the method in the converted system allows information to be retrieved and shared by zooming into a point to reveal information. The same information is presented in the original system and the converted system but the multi-touch aspect should enhance the original learning outcomes and not change them. This question therefore provides data to evaluate if the system meets Goal 4: Ensure the original learning outcomes are maintained after the conversion process.

6. Do you feel direct interaction with a multi-touch surface more engaging with the subject matter than a normal keyboard & mouse?

The final question is aligned with Goal 4: Ensure the original learning outcomes are maintained after the conversion process. This question invites the participant to give a personal comment and describe how the new system is different from the existing system and whether or not the multi-touch, multi-user aspect enhances the learning experience for other users.

6.1.3 Goal and Question Summary

A mapping of the questions to the goals is as follows:

- Question 1. “How would you rate the ease of use of moving and rotating the lens?” maps to Goal 2: Minimise the occlusion caused from an interaction tool but maximise the usability of the interaction tool.
- Question 2. “How would you rate the ease of use of zooming the lens into a point?” maps to Goal 3: Allow the lens to be zoomed into a point for precision selection without affecting the background image.
- Question 3. “How would you rate the ease of use of locking the lens and passing the lens to another user?” maps to Goals 1: Allow multiple users to collaborate over a single static image without altering the image for the other users; and Goal 2.
- Question 4. “To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application?” maps to Goal 1.
- Question 5. “To what extent do you agree/disagree that the ability to context-zoom into a point to reveal information aids with the flow of the system (when compared to the traditional pop-up window)?” maps to Goal 4: Ensure the original learning outcomes are maintained after the conversion process.
- Finally Question 6. “Do you feel direct interaction with a multi-touch surface more engaging with the subject matter than normal keyboard and mouse input?” relates to Goal 4.

<u>Question</u>	<u>Goal 1</u>	<u>Goal 2</u>	<u>Goal 3</u>	<u>Goal 4</u>
1		X		
2			X	
3	X	X		
4	X			
5				X
6				X

Table 6.4 - Summary of the Goal and Question mapping.

The questions presented to the participants on the questionnaire attempt to explain every aspect of the converted system so that the participants can make comments and comparisons with the original system. The questions themselves are ordered in a way that builds up on the complexities of the interface design so that the users can comment at every stage. Each question is aligned to a particular goal and the results of the experiment will confirm if all of the goals have been met and therefore if the research question has been answered.

6.2 Qualitative Evaluation Techniques

Qualitative techniques were used for the evaluation procedure as a focus on free-form comments was deemed an important element of determining if the research was a success. The comments generated in the evaluation could be used to improve sections of the system to improve the overall educational benefit.

The target sample of evaluators included industry professionals and users with little experience of multi-touch systems. The combination of these two groups provided experience from many educational and technological domains and the qualitative feedback gained from them provided a good coverage of the system from their respective backgrounds.

Alongside the use of questionnaires, observations will be carried out to see how the users approach the system and to analyse any problems that arise.

6.2.1 Observation

The observation aspect of the evaluation allowed the researcher to understand how a new user would approach the system. Notes were made on how the user creates a lens and how quickly they discover the various features it provides. Any unusual activity was also documented such as difficulties with interaction of a particular element or technical problems they encountered. The observation evaluation also provided a method to document ideas of future work that users discussed during the evaluation process. This last point was certainly useful for understanding where the system could fit into other domains.

The combination of observations and questionnaires provided a good coverage for the evaluation. The questionnaires allowed every user to provide feedback about the ease of use of the system and document comments about each of the sections. The results of the questionnaire allowed for changes to be made to the system to enhance the usability and the observations allowed future work to be discussed to tailor the system to different domains.

6.3 Threats to Validity

There could be a threat to external validity if the users had previous experience of using multi-touch systems and therefore the results would be less representative of average users. However, the experience provided by the domain users would outweigh the potential threat to external validity as the main goal of the evaluation is to present target market and usability data to TimeMaps.

A limiting factor to this study is that only two sets of participants are used due to time constraints and availability. However, the participants can provide important qualitative analysis based on their domain experience.

For the observation side of the evaluation research bias must be considered. As the researcher is also the developer of the system it may be difficult for them to remain objective when observing users on their system. It is common for researchers in this position to focus the users on the positive aspects of the system potentially

skewing the final data. This threat has been identified and will not take place in the evaluation procedure.

Finally hardware technical limitations may provide a threat to validity. Due to the prototype nature of the multi-touch table hardware several issues may occur during use. The system is being run on multi-touch tables employing three infrared cameras to detect finger touches. Although the tables are calibrated there may be instances where individual finger touches may be doubled between the visual edges of the camera boundaries. This may cause unintended resizing or rotating of a lens. Other technical faults due to calibration may include the finger touch manifesting below the actual location of the finger leading to imprecise selecting of elements. Additionally in the corners of the table the cameras may lose the touch data altogether. These factors can be minimised by ensuring the multi-touch table vision system is fully calibrated before use and that any interaction is kept away from the corners of the screen during use.

The advantage of the observation side of the evaluation is that these technical issues can be addressed if they occur during the user's interaction with the system.

6.4 Summary

In summary the evaluation consisted of both an observation element and a questionnaire containing a set of defined questions that are related to the individual goals defined in section 3.2. The sample frame was split into users with little prior multi-touch experience and professionals who represent the multi-touch industry.

The layout of the questionnaires allowed the users to attempt to answer the questions at any stage of the experiment and the comments sections promoted free-form responses.

Chapter 7 will take the responses gained from the evaluation stage and analyse them to locate trends and attempt to answer the pre-defined goals.

7. Results

The results presented in this section are organised in order of the research goals outlined in Section 3.2. Each goal section will first detail the observations of the users interacting with the system and then explore the results and comments gained from the questionnaires that match the goal.

The experiment took place over 4 days and consisted of the group of industry users on day 1 and the rest of the participants on the remaining days.

The details of the experiment are described in section 6.1 – Experimental Approach.

The questionnaire results are split into three separate sections highlighting the responses gained from the industrial participants and users new to multi-touch (MT) followed by the combination of the results from all participants. The feedback from participants with industrial experience will be used to focus the educational aspect of the system and the results gained from the users new to MT can be used to adjust the interaction aspect of the system.

The combined results take the industry user's results with the data collected from 10 participants selected from the Technology Enhanced Learning department in Durham University. The results published in that section provide statistical validity and more reliability due to the increased sample size and non-industrial review.

Each of the graphs displayed in this section present the data collected from each question. As the results are shown in the order that the goals were described in section 3.2 they are not in the same order as they were presented on the questionnaire. The question number is clearly stated in the heading of each graph and any reference to the results.

7.1 Goal 1: Collaborate Over a Static Image

The first goal aimed to identify how multiple users can collaborate over a single static image without altering the view of the image for the other users by using lens. The goal was defined in section 3.2.1 as:

Goal 1: Allow multiple users to collaborate over a single static image without altering the image for the other users.

7.1.1 Observational Results

Throughout the experiments, the participants were observed using the system. The first group observed using the software were the industry professionals and more specifically, two representatives from TimeMaps. Both participants found the system easy to use and were able to create a lens and move the lens around the screen. One participant did not have previous experience with using touch screens and he commented how easy it was to create a lens, position it over an area of interest and share the point of interest with another user therefore showing the potential to collaborate with another user and meeting goal 1.

Observations revealed that typically a user would draw a lens and zoom into a particular area, lock then lens and then pass it across to another user. Upon passing the lens the original user would then create another lens and explore a different area creating a more than one lens per user scenario. This particular observation demonstrates that the software meets goals 1 and 3 as it combines the ability for users to collaborate over the image but also for a user to precisely select an area of interest and pass the lens containing that aspect of the map to another user for discussion.

7.1.2 Questionnaire Results

The results gained from the questionnaires are split into three sections to highlight the results from the industrial participants and users new to MT followed by the combined results from both groups of evaluators. The results in this section are considered in relation to goal 1 and relate to the data obtained in Questions 3 (How would you rate the ease of use of locking the lens and passing the lens to another

user?) and 4 (To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application?).

7.1.2.1 Industry and New Users to MT - Separate

The questionnaire was completed by 10 industry professionals, from various educational and business backgrounds, and 10 users from the Technology Enhanced Learning group.

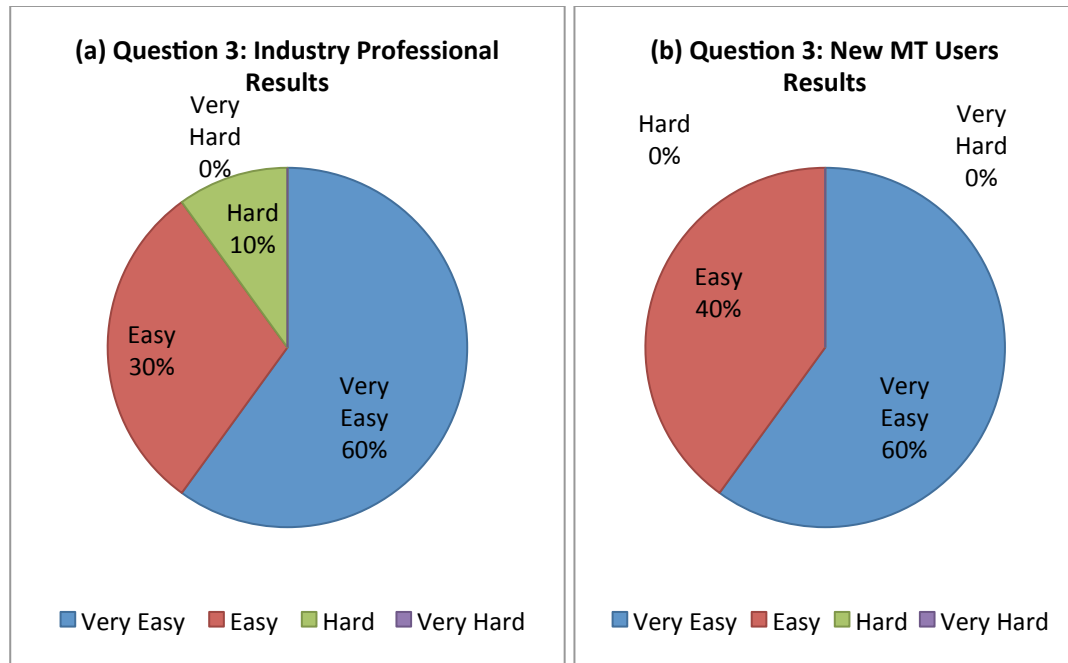


Figure 7.38 (a,b) – 3. How would you rate the ease of use of locking the lens and passing the lens to another user?

In order to collaborate effectively section 2.1.2 noted the need for the users to be able to independently explore parts of the map and to be able to manipulate these without impacting other users. Section 4.2.2 described a design feature termed a lens to activate this function. However for this feature to work effectively the lens must be easy to interact with and easy to pass to another user to share the points of interest discovered. Question 3 asks the participants to evaluate the ease of use of locking the lens and passing it to another user to provide feedback on the collaborative interaction element of the lens system.

Figure 7.38 presents the data from question 3. The results from the industry participants outlined in Figure 7.38(a) show that the majority (90%) of the users

found this interaction easy to use and in Figure 7.38(b) 100% of the users new to MT found the interaction easy to use. The comments detail how the locking and passing ability of the lens would be beneficial to problem solving and holding collaborative classroom sessions. Another comment mentioned the simplicity of this action. The results presented agree with the aims set by goal 1 as the converted system allows multi-user collaboration.

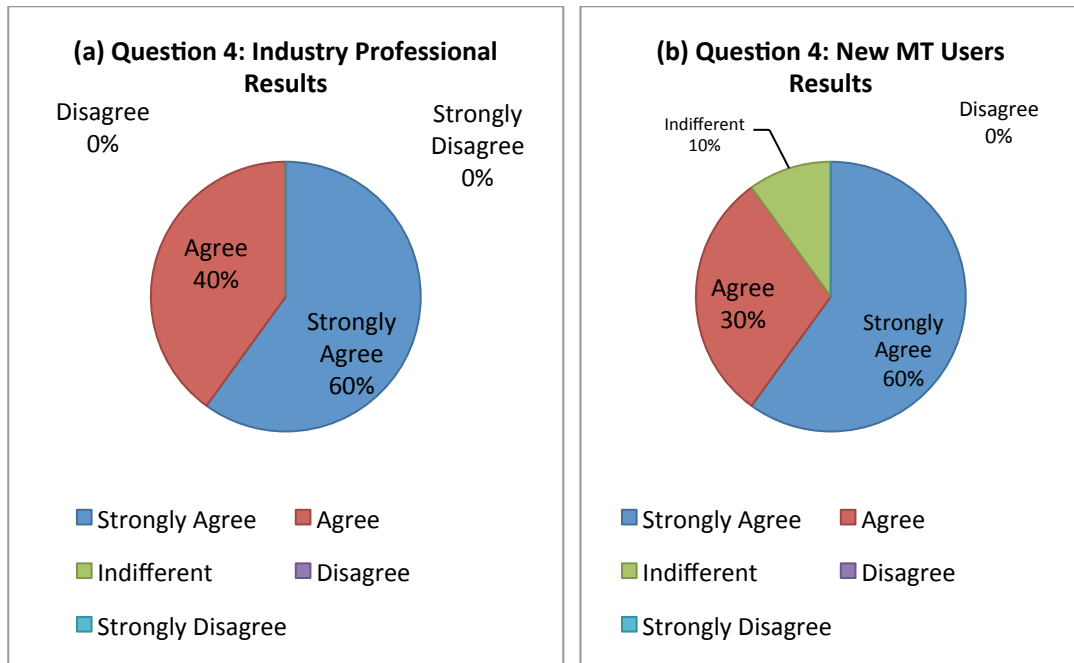


Figure 7.39 (a,b) – 4. To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application?

The benefits of collaboration are outlined in section 2.1.1 but these benefits are only apparent when the issues of friction, frustration and personality clashes are managed (Rentsch & Zelno, 2003). The study by Rick, Harris, et al. (2009), highlighted in section 2.1.2, concluded that the issues can be removed by providing a unified interaction process and this process is subsequently identified as being a multi-touch framework. Question 4 asks the users to evaluate if this application has benefitted from the conversion to multi-touch and if these issues have been resolved.

As can be seen by Figure 7.39, which shows the results for question 4, 100% of the industrial participants were in agreement that this type of application is enhanced by the addition of a framework allowing multi-user collaboration with 60% Strongly

Agreeing and 40% Agreeing (Figure 7.39(a)). Similarly 90% of the users new to MT were in similar agreement with the remaining 2 participants stating they were indifferent (Figure 7.39(b)). The comments that were made highlighted the ability for multi-user collaboration to stimulate discussion and hold the attention of the users for longer and therefore enhancing the learning experience of the subject. Additionally one comment stated “There seems to be a lot of scope to take the idea into different areas” other similar comments made during the observations have been collated and the results can be seen in section 8.2 – Further Work. Further comments suggested that the conversion to multi-user gives the opportunity for critical thinking and therefore this meets the first goal.

7.1.2.2 Combined Results

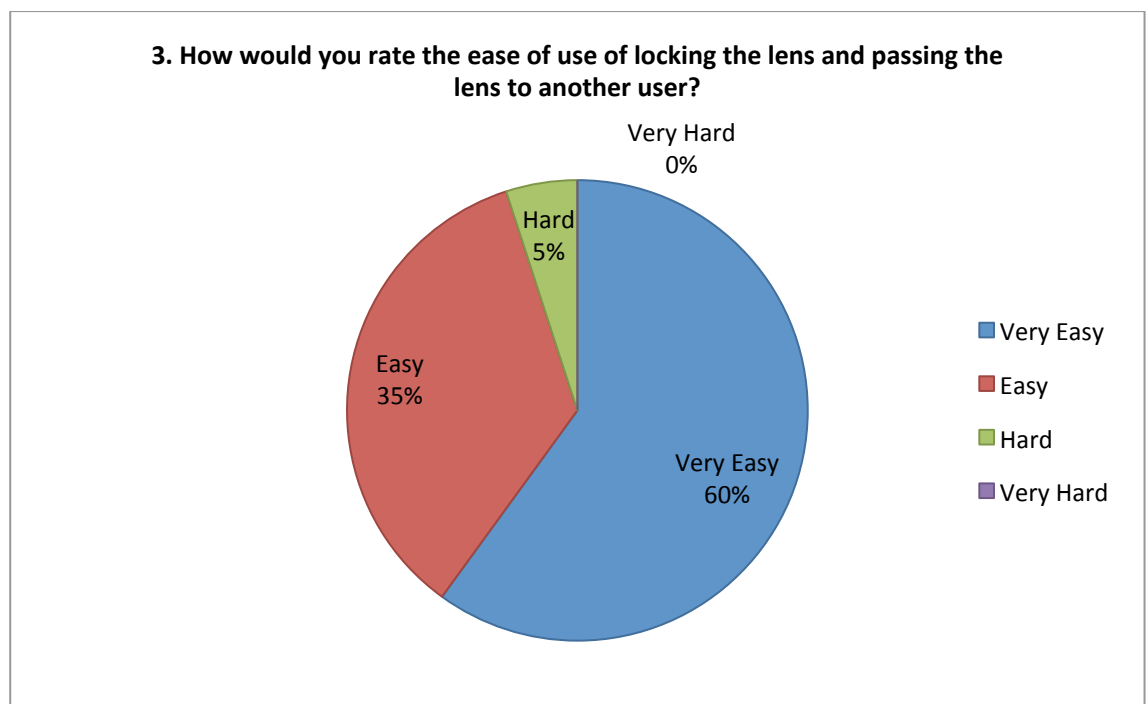


Figure 7.40 – 3. How would you rate the ease of use of locking the lens and passing the lens to another user? (Combined Results).

The combined results from question 3 shown in Figure 7.40 show a positive reaction from all of the participants. 60% of the total participants agree that the ease of locking and passing a lens is Very Easy. The results from the users new to MT cause the only change, which is a 5% deviation away from Hard to Easy. The positive comments from the researchers include: “Simple,” “Very good feature”

and “Simple – a clear button to lock. Passing is quite easy but need to remember to rotate to face the other user, and this is easiest up to 90°, harder around 180°.” Several of the researchers agreed that the ability to flick the lens to another user is beneficial: “Being able to ‘throw’ the lens across the screen helps” and “Very easy to pass to another user” were some of the comments in the feedback.

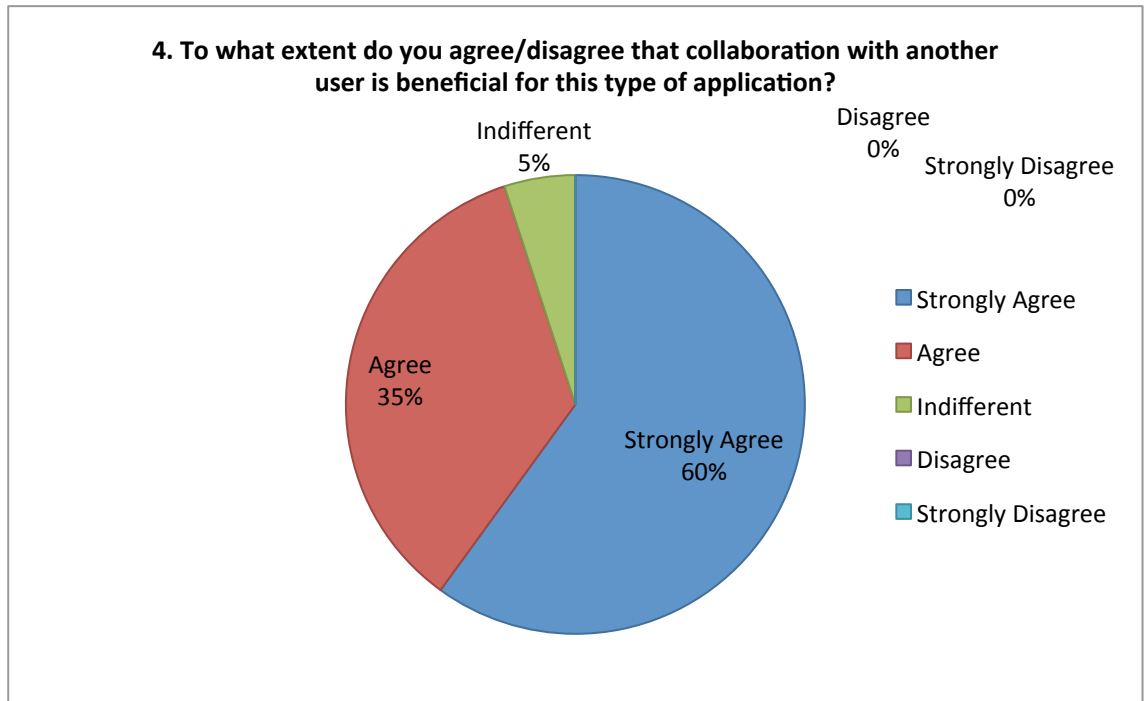


Figure 7.41 – 4. To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application? (Combined Results)

In a similar pattern to Figure 7.40; Figure 7.41, presenting the results of question 4, shows that the combined feedback gained from the researchers and the industrial participants is positive. Again, the ratio for Strongly Agree remains the same at 60% of the total and the positive result is still in the majority with 95%. However, the response from the researchers has created a 5% shift from Easy to Indifferent when the results are combined.

The Indifferent result was commented with: “Not sure, maybe something which a person would rather explore on their own. Not sure collaboration would be needed.” This response will be discussed in section 8 -Discussion.

The majority of the comments placed a strong emphasis on the enhanced collaboration aspect this application offers and this agrees with the first goal as

successful collaboration over a static image is taking place. Some of the positive comments from the researchers include: “One event in history could have affected another so the collaboration encourages the sharing of information about these events.” The ability for collaboration to aid discussion is mentioned in several comments; “Can be used to discuss + learn in groups with the whole group taking part” and “Very good for passing information and comparing findings” are two comments that reflect this.

7.2 Goal 2: Prevent Unnecessary Occlusion by the Lens

The second goal of the research aimed to minimise occlusion from the lens but to maximise usability in terms of speed of selection of points of interest and the reduction of errors from the movement of the lens to these points. The goal was defined in section 3.2.2 as:

Goal 2: Minimise the occlusion caused from an interaction tool but maximise the usability of the interaction tool.

7.2.1 Observational Results

An observation made throughout the experiment was that every user interacting with the system would only create one lens each. On further enquiry into this pattern it appears that the users preferred to work with one lens at a time to preserve the screen space. This shows that the natural reaction by the users is to prevent the occlusion of the background image by the lens as that provides the main point of reference for navigating the lens. In the instances where the users wished to highlight more than one point of interest they were happy to draw another lens on the screen showing that the usability provided by the lenses was more important than the reduction of screen size caused by the creation of a new lens. This agrees with Goal 2 that for each user the lenses they create do not occlude the background image to the extent that navigation becomes a difficult task.

To create a new lens on the screen the users press a button on the menu bar. As this menu bar occludes the background map it can be hidden until needed. An issue that was raised was the difficulty in bringing up the main menu box for a single person. Using the simulator with a mouse and keyboard a simultaneous touch in

the bottom-left and top-right corners would display the menu. However, the multi-touch screen is greater than 40 inches corner-to-corner making is very difficult or impossible for one person to bring up the menu. This issue will be altered in later versions of the software. The feedback on the ability to hide the menu box was positive as it meets goal 2 and prevents occlusion of the background image.

7.2.2 Questionnaire Results

The results in this section are selected to meet the second goal and relate to data obtained for Question 1 (How would you rate the ease of use of moving the rotating the lens?).

7.2.2.1 Industry and New Users to MT - Separate

Section 4.2.2.1 identifies that the main background map provides the key reference for navigation as the map displays the information points for obtaining detail about the respective areas. Occlusion of this map could occur when many lenses are present on the screen if many users are interacting with the system at once. In order to prevent occlusion the design of the lens ensure it contributes a small percentage of the screen space but ensures that the functions can be carried out easily with suitable sized buttons and lens window size. Question 1 asks the participants to evaluate the ease of use of moving and rotating the lens to ensure that the lens can be controlled with minimal error.

The results for question 1 show that out of the industry professionals who participated in the experiment all of them found the lens Easy (50%) or Very Easy (50%) to move and rotate. The results gained from users new to MT show a 70%/30% split between Easy and Very Easy respectively. Some of the comments for this sections detail that the lens moves smoothly and can be finely adjusted with ease. One response indicates that a visual prompt would be useful to inform the user that the lens can be rotated.

The participants stated that the buttons on the lens are of sufficient size so that the lens does not hide too much of the underlying map and that the lens can be rotated in any direction without causing occlusion.

From section 7.1.2.1 the results gained from all of the participants show that the majority of the users found the task of locking of the lens and passing it to another user easy to manage. Some of the users commented on how the flicking action of passing the lens across the table kept the centre of the screen clear so the background map was not hidden by a stuck lens.

These results meet the second goal as any potential means of occlusion from the lens is managed and reduced.

7.2.2.2 Combined Results

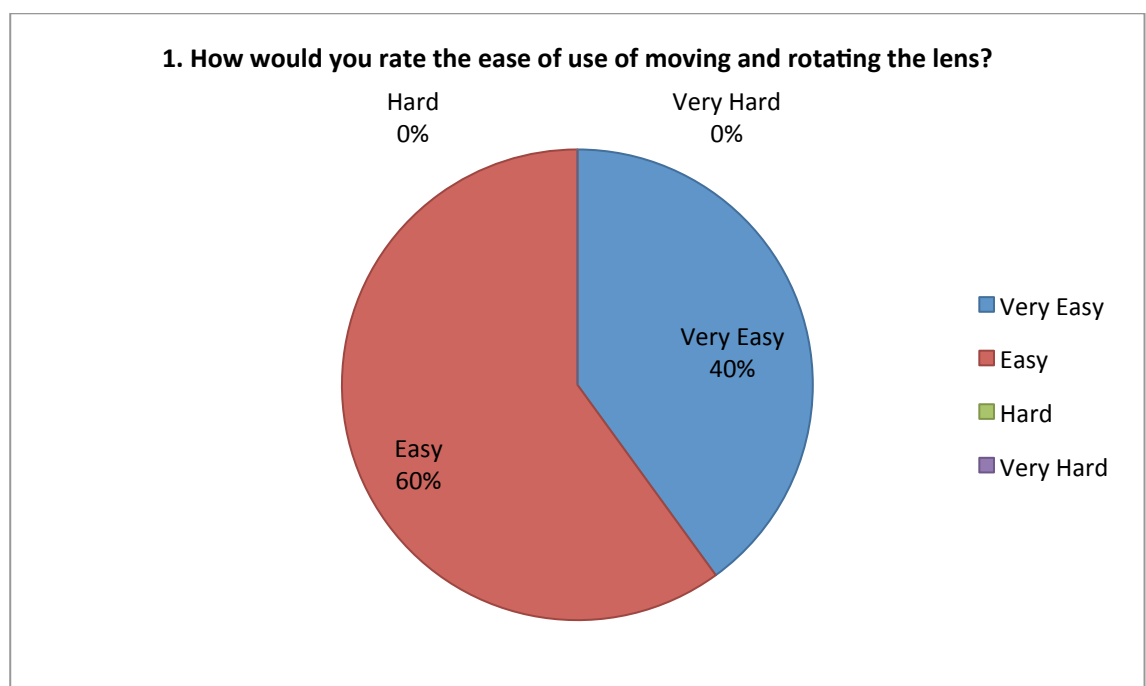


Figure 7.42 – 1. How would you rate the ease of use of moving the rotating the lens? (Combined Results).

As can be seen by Figure 7.42 the overall opinion from question 1 of the ease of use of translating the rotating the lens is still positive with a 60%/40% Easy-Very Easy split.

A few additional comments highlighted technical faults with calibration of the vision system that manifested themselves as low sensitivity on soft presses causing 'jumping' of the selected element: "Rotates easily when the touches are registered, more limited by hardware." Jumping is the action observed when an element does not follow the movement of a finger touch smoothly but moves erratically around

the area where the finger is pressed. However, when the technical faults are not apparent the lens translation and rotation becomes “very easy and fluid and quite fun.”

From section 7.1.2.2 the results gained from the participants show that the majority of the users found the task of locking of the lens and passing it to another user easy to manage with only 2 participants finding it difficult. The users commented on how the flicking action of passing the lens across the table kept the centre of the screen clear so the background map was not obscured.

These results meet the second goal as any potential means of occlusion from the lens is managed and reduced.

7.3 Goal 3: Allow the Lens to be Zoomed for Precision Selection

The aim of goal 3 is to allow the users to zoom into an image of larger resolution than the display to uncover points of interest without affecting the image for the other users. This goal was defined in section 3.2.3 as:

Goal 3: Allow the lens to be zoomed into a point for precision selection without affecting the background image.

7.3.1 Observational Results

The context-sensitive zoom aspect of the research was especially appealing to the TimeMaps representatives as it was an alteration of their standard point-and-click single-user system and provided “a much more fluid way to interact with the presented information.”

The group consisting of multi-touch hardware developers understood the mechanics of the research and had little difficulty with creating and manipulating the lens. One user in this group did mention that the zoom slider was difficult to understand because he was not sure if he should attempt to slide the red side of the slider or the white side. This point was also raised by another user in the questionnaire stage. The participants in the DTLens (Forlines, 2005) study, which provided the basis for this slider bar, were all domain experts and this difficulty was not mentioned in that paper.

The observations show that the goal for allowing precision selection through zooming was met. The TimeMaps representatives found the zooming features appealing and other users found it straight-forward and easy to maintain a thought process due to the lack of a complex interface to navigate.

7.3.2 Questionnaire Results

The results in this section are selected to meet the third goal and relate to data obtained for Question 2 (How would you rate the ease of use of zooming the lens into a point?).

7.3.2.1 Industry and New Users to MT - Separate

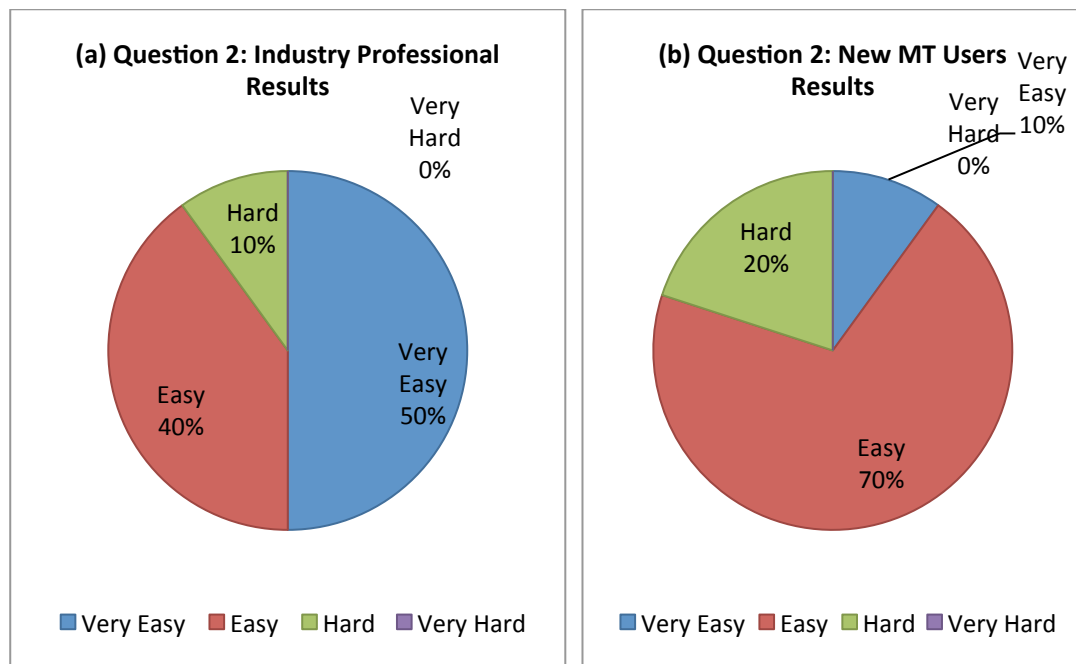


Figure 7.43 (a,b) – 2. How would you rate the ease of use of zooming the lens into a point?

The problems of selecting a point precisely using a touch-screen are noted in section 2.2.3. In this system the users would need to select an information point such as one that may contain details about a particular village when the default view is a map of a continent. Section 2.4.1 identifies a way to zoom into a map to reveal more information using a scroll bar and a zoom window. When the user zooms into a particular point on the map an information point would become

easier to select. Section 4.2.2.1 described a design feature built into the lens that allowed the user to apply a touch and a finger movement to the scroll bar to change the zoom level of the image in the lens. For this feature to work effectively the user should be able to zoom into an information point to reveal finer detail and to zoom back out again fully. Question 2 asks the participants to evaluate the ease of use of zooming the lens into a point to reveal more information.

The positive result was pleasing as this method is the most used within this application for navigating around the system and precisely selecting a point. A response of 90% from the industry participants gave feedback stating that the research system was either Very Easy (50%) or Easy (40%) to use. This is shown in Figure 7.43(a). The 2 participants that gave the response Hard commented that it was not obvious which side of the zoom bar to use, a response that was observed by another participant. 80% of the users new to MT found the research system Very Easy (10%) or Easy (70%) to use with 20% stating that it was hard to use (Figure 7.43(b)). Comments from the users new to MT echoed the comments from the industry stating that it was often difficult to know which bar in the zoom area to press.

These results show that the lens can be zoomed into a point easily with little error and therefore the aims of goal 3 are met.

7.3.2.2 Combined Results

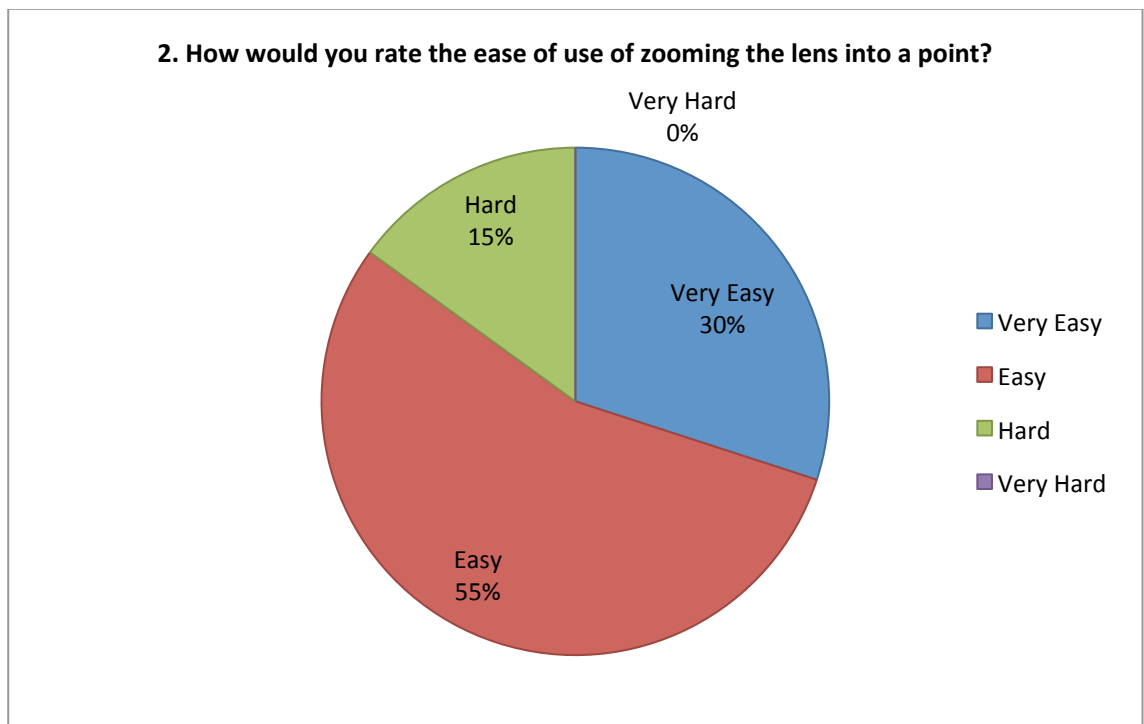


Figure 7.44 – 2. How would you rate the ease of use of zooming the lens into a point? (Combined Results).

The feedback gained from the users new to MT has altered the combined data slightly and this is presented in Figure 7.44 displaying the response from question 2. As can be seen there is a 55% result for Easy and at the top-end the result for Very Easy is 30%. The overall result is positive with a majority of the responses (85%) responding with Easy or Very Easy. A result of 15% can be seen for the response Hard. Some of the responses for this increase appear to be due to the confusion between the red and the white areas of the zoom slider. “Have to press within [the] red bar, won’t work in white section to zoom out quickly..”

A similar problem appears when trying to use the zoom slider when it is positioned near the bottom of the screen as the touch calibration is off in this area. “Input rarely registered, zooms well when it is” and “Calibrated, it would probably be very easy” are some of the responses from users manipulating the lens in the bottom zone of the surface.

These results agree with the aims of goal 3 and allow the lens to be zoomed into an area of interest for precision selection.

7.4 Goal 4: Maintain the Learning Outcomes through the Conversion Process

The fourth goal aimed to ensure that the educational learning outcomes are maintained when the system is converted to multi-touch. This goal was defined in section 3.2.4 as:

Goal 4: Ensure the original learning outcomes are maintained after the conversion process.

7.4.1 Observational Results

As seen in section 7.3.1 TimeMaps discussed how the converted system matched the learning processes of the original system. In the original system the user could select information points to view pop-up boxes containing the learning material. In this research system the users can zoom into a point to view the information in the lens. The TimeMaps representatives stated that the information contained in the converted system was maintained but the new multi-touch interaction method allowed “a much more fluid way to interact with the presented information.” This agrees with goal 4 as the learning outcomes have been maintained after the conversion.

The teachers commented that they were impressed with the potential scope of the research and how it could be tailored for other subjects as well how they could see this system installed in schools around the country.

An interesting point to note is that all of the participants chose to stand up when using the system even though chairs were provided. Although this may have been due to the social situation where the participants were communicating to others not directly involved with the multi-touch table, one participant explained that it was easier to see all the points of interest across the whole map by looking down on the screen as opposed to looking across it in a seated position allowing for greater involvement with the subject material.

7.4.2 Questionnaire Results

The results in this section are selected to contribute to the fourth and final goal and relate to the data obtained in Questions 5 (To what extent do you agree/disagree that the ability to context-zoom into a point to reveal information aids with the

flow of the system (when compared to the traditional pop-up window?) and 6 (Do you feel direct interaction with a multi-touch surface more engaging with the subject matter than normal keyboard and mouse input?).

7.4.2.1 Industry and New Users to MT - Separate

Section 3.1 outlines the traditional TimeMaps application construction and the interaction design of the existing systems. To reveal information about a particular area in the existing system the user clicks with a mouse on highlighted points to reveal a pop-up window containing detail about the area of interest. This section noted that the pop-up window uses a large area of the screen and only one pop-up window can be displayed at once presenting a problem for multi-touch conversion. In order to conserve this process after the conversion section 4.2.3 identified a method called context-sensitive zooming that allows the user to position the lens over a point of interest and zoom in using the slider bar until the image displayed in the lens changes to present the contextual data. This method allows many users to interact with different information points because the pop-up information windows are localised to the individual lenses. Question 5 asks the participants to evaluate how this new method of revealing data differs from the traditional start-stop approach of selecting an information point, reading the details in the pop-up window and then closing the pop-up window.

The results in this section highlight how the information from the single-touch system has been converted into multi-touch. This combines areas of the research that allow the user to interact to gain the information as well as the display format of the information.

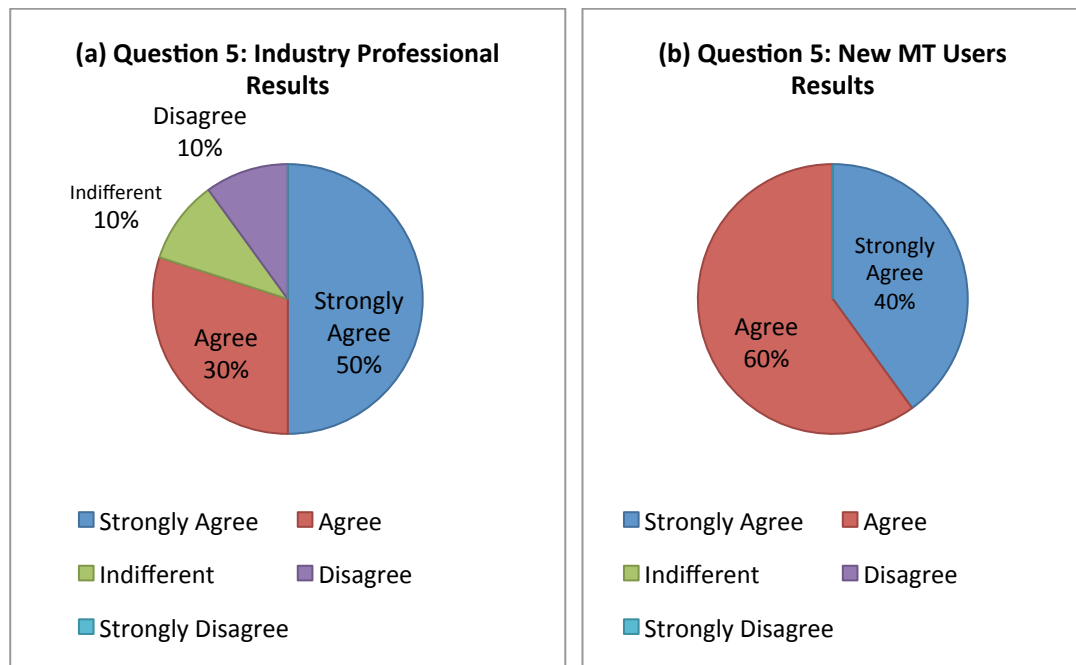


Figure 7.45 (a,b) – 5. To what extent do you agree/disagree that the ability to context-zoom into a point to reveal information aids with the flow of the system (when compared to the traditional pop-up window)?

Figure 7.45 shows the results from question 5. The context-zoom is an extension of the previous control elements and combines them to provide another part of functionality relevant to this research. This question was preceded by a demonstration of the original TimeMaps system where a single user clicked on an information point and a pop-up window appeared in a traditional software sense to provide a basis for comparison. The results obtained for the industry participants were more diverse this time but the majority (80%) still Agreed (30%) or Strongly Agreed (50%) that the context-zoom aided with the flow (Figure 7.45(a)). 10% Disagreed that context-zoom was an aid and 2 participants were indifferent. All of the new users to MT participants were in agreement (60%) or strong agreement (40%) that context-zoom aided the flow of the system (Figure 7.45(b)).

Many of the comments suggested that the context-sensitive zoom was beneficial to this research system and aided the interaction flow. However many users said they would like to see a study conducted to investigate if the usability of other multi-touch applications is enhanced using this research. Another comment stated that the context-sensitive zoom “opens up the possibilities for students to ‘discover’ for

themselves.” One of the teachers from the local education authorities commented that this feature could be “applied in a lot of contexts across the curriculum.” The 2 participants that disagreed with this question suggested that the context-zoom works with this system as the information points are highlighted on this screen. If the points were not made clear “time could be spent searching..need icons/markers at top level to indicate areas of interest.” The ability to context zoom into an information point does not break the interaction flow when compared to the traditional point-and-click system and the information displayed provides the same learning outcomes as the original system therefore the final goal is met.

Section 2.2.1 presented a quote from Shneiderman (1991) that stated “Touchscreens have...a rewarding sense of control, and the engaging experience of direct manipulation.” This rewarding sense of control and engagement with the subject matter combined with the collaborative aspect identified in section 2.1.2 should allow the user to become more involved with the subject displayed on the screen and therefore prevent distraction and enhance the learning outcomes. Question 6, invited the users to agree/disagree and comment on whether they thought the multi-touch surface allowed them to engage more with the subject matter than a traditional keyboard and mouse.

All of the industry users agreed that the multi-touch surface was more engaging and some of the comments given included: “I felt this was one of the strongest parts of the app. The engagement would surely stimulate discussion.” One of the members from the local education authority stated: “Young people would find this hugely engaging.”

7.4.2.2 Combined Results

The questions asked to obtain the following results move away from the basic manipulation of the system and ask the participants to evaluate how the research system can aid the flow and understanding of the information present in the application.

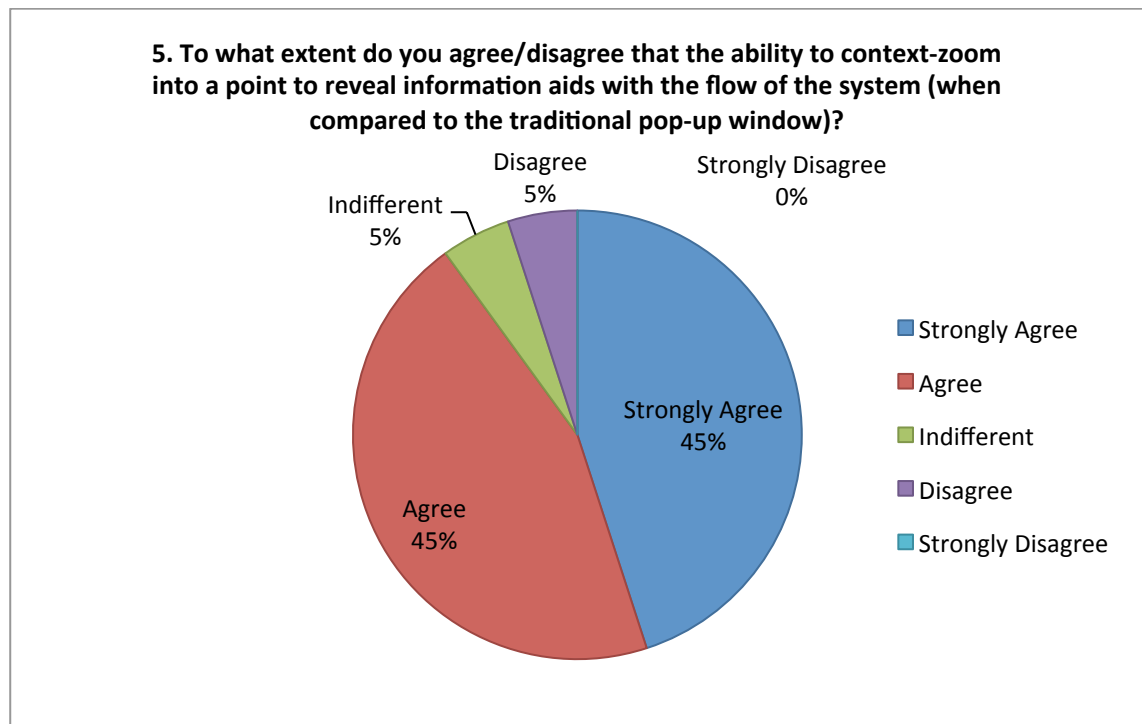


Figure 7.46 – 5. To what extent do you agree/disagree that the ability to context-zoom into a point to reveal information aids with the flow of the system (when compared to the traditional pop-up window)? (Combined Results).

The main feature of Figure 7.46, detailing the results of question 5, is the even split between the Agree and Strongly Agree response with 90% between the two. This is due to 60% of the new users to MT in Figure 7.45(b) Agreeing compared to the 30% of the industry participants Agreeing and the even split between Indifferent and Disagree from the industry participants (Figure 7.45(a)).

The majority of the comments state that the context-zoom is flexible and dynamic for the TimeMaps interactive map purpose but others would like to see a study into other subject matters using the lens. Many of the participants were impressed with how the context-zoom prevents data occlusion when compared to a traditional pop-up window. “Having a movable lens with zoom allows an overview of the entire map/project so other information points are less likely to be missed or forgotten than if a popup window [was] covering them.”

One participant mentioned a hybrid solution to the pop-up window and context-sensitive zoom options: “Might be nice to combine both...Zoom into reveal several

info points and then pop up the selected one.” This response will be covered in section 8 - Discussion.

Other responses stated that the context-zoom was slower to reveal information compared to clicking a pop-up box, but this “combined with the ability to lock, rotate and pass makes this well worth it.”

Two responses stated that this form of information revealing felt more integrated with the content and helps to prevent losing the context. These results meet goal 4 as the learning outcomes are maintained from the original single-touch system but are enhanced by the multi-touch interaction.

As before, question 6 maintained a 100% positive response rate which means all participants felt that the multi-touch aspect of the research was more engaging with the subject matter than normal keyboard and mouse input. Some of the comments from the researchers included: “It is more physically engaging so intrinsically more engaging,” “It is much more natural and informal in a group setting” and “Much more intuitive for tasks such as rotation of images. Less fatigue than moving around with a mouse.”

One researcher mentioned the technical limitations in response to this question and stated that “Yes but it depends on how it responds to the input (accuracy etc).”

7.5 Summary

The results show that all of the goals described in section 3.2 have been met. The lens tool allows users to explore areas of a map individually and to lock these areas to pass to another user and collaborate over points of interest. The lens has been designed in such a way that the buttons are large enough to allow interaction without error but small enough to prevent occlusion even if a user draws two or more lenses.

The zooming feature of the lens allows the user to select a point with precision therefore agreeing with goal 3. The context-sensitive zooming also ties together goal 3 and 1 as it allows the user to zoom into an area of interest, lock the lens and then pass it to another user to work together collaboratively on that point. Finally, the representatives from TimeMaps found that the zooming ability of the lens

allows the learning material to be presented to the user in a more accessible way
but the learning outcomes have been maintained throughout the conversion
therefore meeting the final goal.

<u>Result</u>	<u>Goal 1</u>	<u>Goal 2</u>	<u>Goal 3</u>	<u>Goal 4</u>
Observational	Users showed immediate ability to draw a lens and share the results with other users	The users preferred to create 1 lens at a time, which prevented occlusion of the underlying map.	Users found the zooming features appealing, straight-forward and easy to maintain a thought process due to the lack of a complex interface to navigate.	The TimeMaps users stated that the information contained in the converted system was maintained but the new multi-touch interaction method allowed “a much more fluid way to interact with the presented information.”
Questionnaire	The majority of participants agreed that this educational application is enhanced by the collaborative nature of multi-touch	The participants stated that the lens and the buttons are of sufficient size to aid usability but prevent unnecessary occlusion.	The majority of participants found the process of zooming into a precise point easy with a small number find the zoom slider confusing	All of the users agreed that the ability to zoom into a point to reveal further information aids the flow of the system compared to traditional single-touch methods.
Summary	The ease of use of the system and the fluid interaction of creating and passing a lens are the primary reasons that the users found it easy to collaborate over a static image with other users.	The results meet goal 2 as any potential means of occlusion from the lens is managed and reduced with users finding the lens a suitable size to inspect the static image with more detail without unnecessary occlusion.	The results agree with the aims of goal 3 and allow the lens to be zoomed into an area of interest for precision selection.	All of the industry users agreed that the multi-touch aspect was more engaging and some of the comments given included: “I felt this was one of the strongest parts of the app. The engagement would surely stimulate discussion.”

Table 6.5 - Summary of Results

8. Discussion

The following section will analyse the results obtained from the evaluation and discuss any patterns or points of interest that have arisen.

8.1 Overview

The results show that the participants on the whole found the research system easy to use and the experience more beneficial for learning about the subject matter. As the research system was based around an existing TimeMaps history application a few comments highlighted that some participants would like to see how the results might change if the subject of the research was changed. One of the industry participants from the local education authority said that he would like to see the application built upon a biology basis. For example, the users would see an image of a leaf as the main background image but when zooming into the leaf with a lens, the users could see more detail based on their educational level. GCSE students could zoom up to the level of the contents of a leaf cell and understand how each component of a leaf cell operates such as the cell wall and the chloroplasts. This idea could be extended for AS and A-Level students so that they could zoom in even closer and view the leaf at a molecular level and see the interaction of the Golgi apparatus during mitosis.

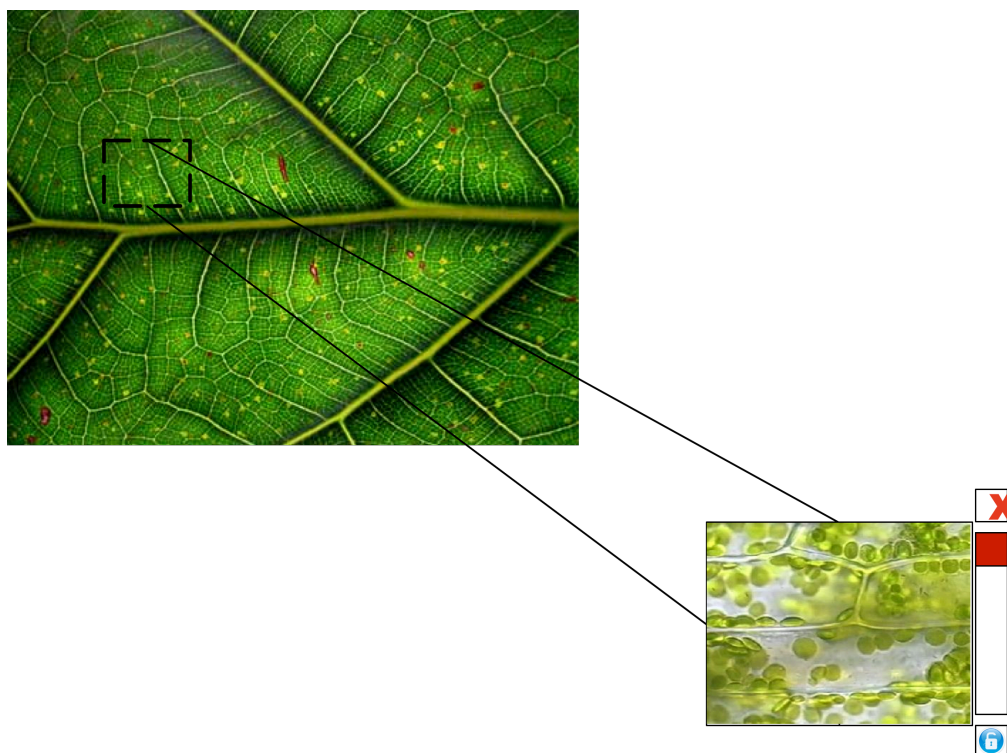


Figure 8.47 – Diagram showing the potential use of the jLens system with a GCSE biology context. (Images from FirstScience.com)

8.2 Responses of Interest

A couple of the combined participants commented under question 4 (To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application?) that they would like to see a study carried out to see what applications the jLens research would and would not work with.

When comparing the results between the researchers and the industry participants it can be seen that the researchers are overall more critical in their responses. This is true for all of the questions apart from 3 (How would you rate the ease of use of locking the lens and passing the lens to another user?) where the response for Easy increased by 5% to 35%. A possible explanation for this is that the researchers that took part in the experiment were used to providing more objective, critical responses whereas the industry participants had come from different backgrounds. As the task of locking the lens and passing it to another user is the most involved task in relation to multi-touch in the evaluation, it is the most vulnerable to

technology faults and user error. This may be a reason why the results were more positive from the researchers for this question.

The majority of the responses from both parties for question 4 (To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application?) were positive apart from 1 researcher who responded with Indifferent. The comment under this response was: "Not sure. Maybe something which a person would rather explore on their own, not sure why collaboration would be needed."

This response highlights the potential uses of the research for individual users as well as for group work. During a discussion with the participant he suggested that users could also use the application in a single-user, multi-touch configuration so that the individual user can interact with the system and learn about the subject matter on their own accord. This idea was echoed by one of the industry participants from the local education authority who suggested that during a lesson, in which this research is implemented, the teacher could guide the students through a certain area of the subject and set a piece of work that allowed the students to explore the system in their own time. This is suitable use for the research as the direct interaction aspect of multi-touch is an aid to learning regardless of the multi-user collaborative aspect.

A response of interest that could lead to a further investigation was given by one of the research participants for question 5 (To what extent do you agree/disagree that the ability to context-zoom into a point to reveal information aids with the flow of the system (when compared to the traditional pop-up window)?). The comment suggested that the combination of a traditional pop-up window and the context-zoom feature would lead to interesting observation as a user could context-zoom to a particular point and then select a point within this zoom to pop-up some information. This may combine the ease of use with zooming into a point with the rapid response of selecting a feature to bring up a pop-up window. This is especially true if the zoomed view is crowded with many points making it hard to differentiate between them. This response agrees with the work by Sears and Shneiderman that examines the time taken to select points of different sizes and dispersions on a touch screen (Sears & Shneiderman, 1989). This work combined with a study of

using the jLens research to zoom into a point could be used to find an optimal combination of the two interaction methods.

8.3 Trends

The major patterns in the results show that the responses were positive for all of the questions. The combined results show that the views of the researchers were similar to the industry professionals with some subtle differences. The most prominent of these differences was the researchers finding the manipulation of the multi-touch elements easier than the industry participants.

The most common criticism with the research system is the difficulty with using the zoom slider as the results show it is confusing to know which side of the bar to interact with. Perhaps a future edit could be made that would allow the white side of the bar to be moved as well, or make a change to the red bar to make it more prominent for the users. A similar issue was experienced by the users when they attempted to move the zoom slider by pressing on the join between the red and white sides of the slider. As Wang & Ren (2008) discovered the average surface area of a human finger touch is 396.8mm^2 whereas a mouse cursor operates on a pixel-by-pixel basis. This makes the interaction with the zoom bar difficult as the user does not have fine control over the desired point to select using a finger touch.

The final trend is the response by both sets of users detailing their agreement that the research aids with multi-user collaboration for certain subjects, such as the TimeMaps history example, and how it is possible to visualise if a subject would work with the jLens research on a per-case basis, but there are no firm rules on what elements are required in the subject matter before the system enhances the learning potential or potentially weakens it.

8.4 Research Question

The original research question set out to answer and investigate if a single-user, single-touch system can be successfully converted into a multi-user, multi-touch system. The research question was previously defined as: *“How can an existing single-user, single-touch educational system be converted to multi-user, multi-touch while maintaining the learning outcomes of the original system?”*

By using a modified TimeMaps application as the base of the study, usage results and successes/failures of their existing systems can be compared with the jLens research. This is helped as TimeMaps applications are already documented and feedback has been received in previous studies carried out by the company. The end result of their research was a single-user, single-touch software framework that is successful when used in an educational environment to enhance learning of particular historical episodes.

With this original system as the framework for the project several potential variables could be kept constant, such as the screen layout, icons, original images and their placement as used in TimeMaps applications. The variables that were changed were elements that converted the interaction system into multi-touch and allowed multiple users to interact with the application at the same time. By doing this, the results gained allow a direct comparison with the original TimeMaps software to evaluate if the research is a success.

By looking at the results the overall response was positive in the evaluation. The questions posed to the participants asked them to add comments about the ease of use of the multi-touch elements as well as if the elements combine to add a useful multi-touch layer for multi-user collaboration. In particular question 4 (To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application?) allows the user to explore whether the research now works well in a multi-user environment. The results show that 95% of the participants were in agreement or strong agreement that collaboration was useful for this application. This combined with the predominantly positive results for the other questions, which detail the multi-touch nature of the research, show that the single-user, single-touch to multi-user, multi-touch system conversion was a

success in this research. The overall theme gained from the comments state that the new system is easier to use than the previous system and the multi-user collaboration aspect makes it more engaging for the users.

8.5 Summary

In conclusion the participants saw real scope and potential to extend the current implementation of JLens. The idea that the system could be expanded further into the teaching space by occupying different subjects shows that the JLens framework is definitely customisable and this is demonstrated by the biology lesson example in 8.1 - Overview.

Some of the responses of interest highlighted further areas of study and the possibility of using JLens in a single-user multi-touch configuration to explore and understand complex ideas using the positive features of multi-touch to explore subjects in more detail without the concern of a traditional GUI to navigate.

Overall the participant's responses were positive over both groups with a slight difference in the researchers finding the manipulation of the multi-touch elements easier than the industry participants. Further study could be carried out into the usability of the zoom bar due to the difficulty in selecting a precise zoom level with a human finger.

The combination of the positive participant results combined with the suggestions for possible adaptations of JLens show that the single-user, single-touch to multi-user, multi-touch system conversion was successful in this research.

9. Conclusion

The conclusion will detail any limitations with the jLens software, further work to expand the aims of the jLens software and the limitations of the evaluation

9.1 Software Limitations

This section aims to discuss the limitations with the software used and created during this research. The removal of these limitations followed by a repeat of the evaluation may create more accurate results in future experiments.

9.1.1 Synergynet Framework

The objective of jLens is to provide a framework that can be used to aid multi-user collaboration of a single static image in an educational and industrial environment. For a system such as this to become conventional within these communities several changes need to be made to how multi-touch software is developed and executed. Firstly the ease of developing these applications needs to be addressed, currently Synergynet, the framework that was used to develop jLens, is Java based and therefore has advantages such as ease of programming but also disadvantages such as slower execution and non-native operating system support.

Ideally, if a multi-touch application could be developed on an operating system that supports native multi-touch interaction with APIs and library calls then other programming languages could be used that allow the look-and-feel of the operating system to be maintained in an application. The advantage of this is that the developer could have access to a large number of multi-touch elements, such as lists, text boxes, rotatable windows and many other widgets useful for multi-touch content creation and the final application could be easily deployed to other users of multi-touch surfaces using stand-alone executable files.

9.1.2 Lens Interaction

One of the interaction queries discovered during the evaluation was the user's expectation of using a pinch gesture (where two fingers are moved towards or away from each other) on the lens itself. Currently there is no manipulation process in place so the pinch/resize gesture does nothing. During the observation stage of the evaluation, the users that commented on this lack of interaction were split on suggesting two types of event.

9.1.2.1 Resizing the lens

Some of the users suggested that performing the pinch gesture should resize the lens to take up less space on the screen. If the lens is locked in this state then the locked image will remain fixed in relation to the scale factor. If the lens is unlocked then the image will not change and remain freeform.

The feedback gained suggested that this would be very useful if the area of an interest takes up a small proportion of the lens viewing area and therefore the whole lens could be resized to increase the amount of usable screen space.

9.1.2.2 Scale the Image

Other users suggested that the zoom gesture could be used to zoom into the image in the lens and therefore negate the need for a zoom slider. The advantage with this idea is that the interaction becomes more natural and follows the notion of direct interaction in a more involved way. Also, the zoom slider bar could be removed and therefore more screen space would be available for the users.

However, it was discussed that perhaps the zoom slider is an important feature as it allows the user to gauge how far they are zoomed down into an image. When context-sensitive zooming is used it can become quite difficult to work out what level the lens is zoomed to as the image in the lens can change and the background image can become obscured increasing the difficulty further.

As the interaction surface of the lens consists of only one main area, just one of these gesture events could be implemented. Additionally because on further investigation the zoom slider is a useful addition to help the user locate where they

are on the zoom scale, perhaps the ability to resize the lens window could be a further improvement.

9.1.3 Lack of Timeline

One of the features on a TimeMaps application is the ability for the user to move through a timeline by clicking on two arrows in the top-left of the screen (Figure 9.48).

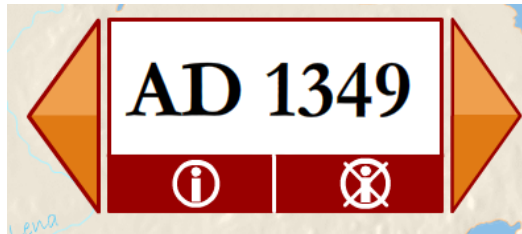


Figure 9.48 – The timeline control in a TimeMaps application (TimeMaps, 2009).

This is a suitable solution for a single-user environment as the solo user can decide when it is time to move through the timeline and change the map. For the purposes of the evaluation, the timeline slider was removed and the experiment was conducted on one static map from a timeline to test the multi-touch, multi-user elements for a variety of educational subjects.

A problem occurs when the timeline is incorporated within a multi-touch application as only one user can interact with it in its current form whether that user makes a decision of their own or on behalf of the team. This could potentially allow a timeline to progress before a user is ready to move on. Several solutions to this limitation exist and one of the most suitable is discussed in section 9.2 - Further Work.

9.2 Further Work

The design and evaluation of the research has highlighted many areas that the research could extend into from increasing the multi-user collaboration aspect to adding additional layers to the application. The extension ideas are detailed in this section.

9.2.1 Networking

The final jLens research system allows for multi-user collaboration around a single-user system. When the application is used in a classroom environment there is the scope to enable the application to use networking across multiple multi-touch tables to provide multi-user collaboration around an individual table and multi-user collaboration across a classroom between different tables. Further research would need to be carried out to determine the advantages and disadvantages of this enhancement but a couple of the industry participants from the evaluation explained a possible example of the solution.

If a multi-touch classroom contained 4 tables and each was surrounded by 4 or 5 pupils then the extension to the jLens application could allow one subject to be taught over the tables with each table displaying a different section of the lesson. If the subject being taught with the tables is history and the topic is World War II, then each table could potentially provide a view of a continent or individual country. The teacher could set a task to the pupils and around each table the pupils could find some information about the continent or country they are working on. The pupils on one table could create a lens and lock some information, that is useful for the set task, and pass this locked lens to another table across the network giving a seamless transition from one table to another. When the second table has finished with the information, the lens can be thrown back to the originating table. This is shown in Figure 9.49.

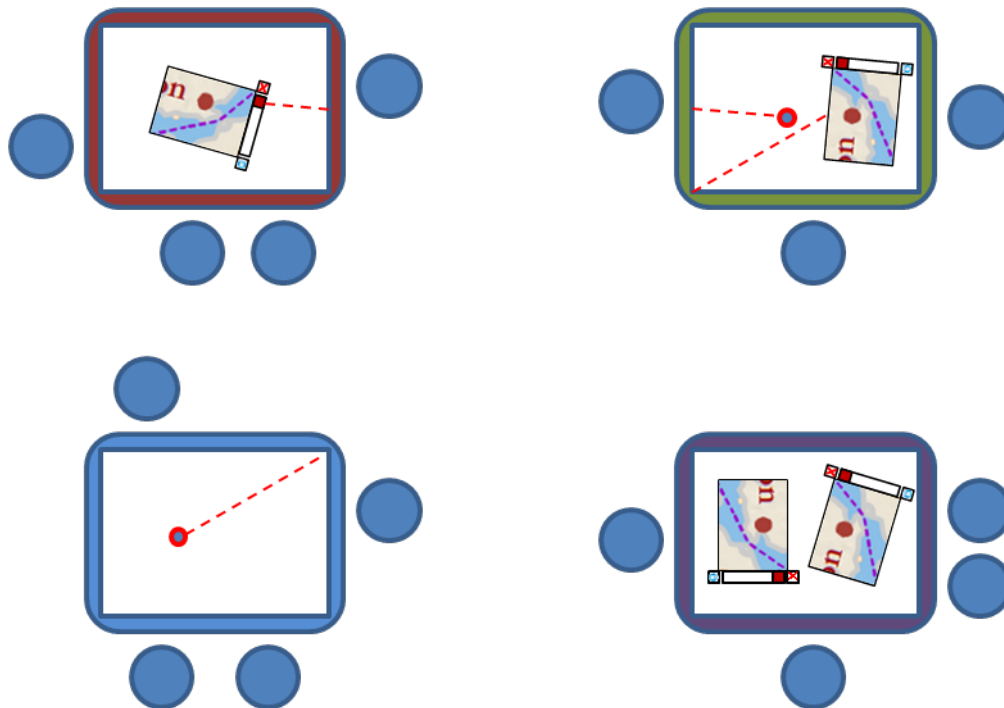


Figure 9.49 – Diagram showing the potential for jLens running a networked subject. The blue circles represent pupils surrounding four tables delineated by different colours. In this example, the top-right table has ‘flicked’ a lens across to the top-left and they are also viewing a lens from the bottom-left.

9.2.2 Collaborative Image Change

As discussed in section 8.1.3 certain application, especially timeline-based history applications require the ability for the user to cycle through images when one image has been explored and the user wishes to move on. This raises a collaboration issue as traditionally only one user can decide when to change the image whether it is in collaboration with the other users or not.

One solution to this problem, which allows an image to be changed when all the users are ready to move on, is to edit the lens window. By adding a ‘ready box.’

When each user has drawn a lens, navigated around the main image and is ready to move on they can press the ready button in the lens window Figure 9.50. The program will know how many lenses are present on the screen and when every one of the ready boxes has been selected the image will cycle (Figure 9.51).

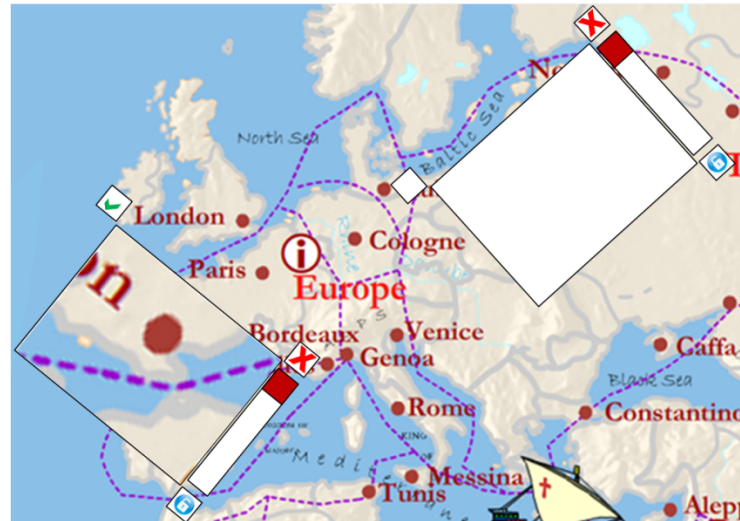


Figure 9.50 – Diagram showing the implementation of a ready box positioned on the top-left of every lens. The lens on the left of the screen is in the ready state.

The lens on the right is not.

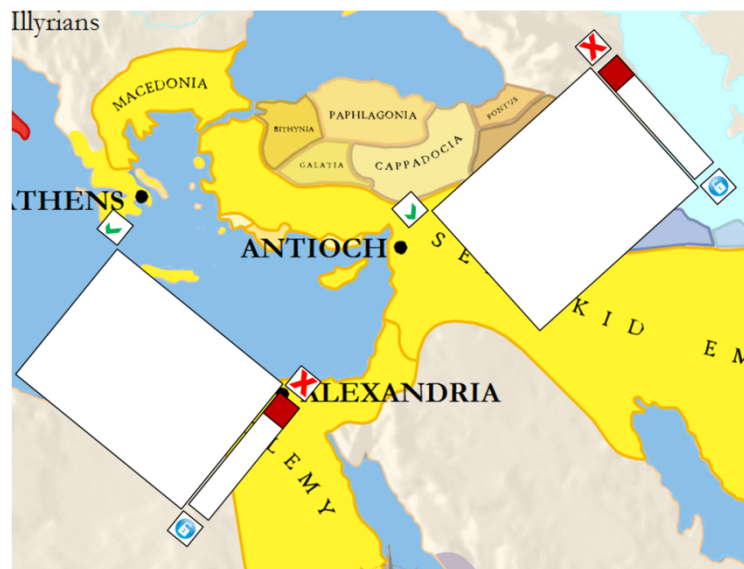


Figure 9.51 – Diagram showing the transition stage after all the lenses have entered the ready state. The main image has been changed and the lenses are in the process of being removed in readiness for new lenses to be created on the new image.

The advantage of this system is that every user is required to input their ready state before the image can be moved on. However, the biggest disadvantage is that this method only works with the notion that there is strictly one lens per user. If a user has just closed a lens then the remaining users have the combined power to change

the image before the first user has the chance to draw another lens on the screen. Also, if one user has created several lenses then they have to select the agreement box on all of the lenses that they have opened. This problem is compounded further if the lens from one table is passed to another table as discussed in section 8.2.1. In this instance the users on the other tables would be able to intervene and potentially cycle the image from another table.

9.3 Limitations of Evaluation

As the end result of the implementation and design of this research was an interface system the evaluation method was limited by the difficulty in obtaining quantitative data. This section details that limitation.

9.3.1 Evaluating Interface-Centric Systems

One of the difficulties in evaluating an interface-based system such as jLens is the difficulty in obtaining quantitative data due to the varied nature of the usage of graphical interfaces. As the system provides a framework for engaging with a large image it is predominantly a front-end interaction solution and is therefore not exposed to running times or other critical factors that could be measured and repeated for a quantitative evaluation.

However, because the usefulness and success of the research is based on user opinion and collaborative interaction with the subject matter, the importance of qualitative feedback from user opinion is great. As the questions asked of the participants during the evaluation were carefully selected to highlight important usability issues (such as lens manipulation and ease of multi-user collaboration) and because the end results were positive, this shows that the final product was suitable for the aims it set out to achieve.

9.4 Final Conclusion

To conclude, the subject of multi-user collaboration has been greatly debated in recent years with the creation and maturity of multi-touch displays and multi-user content creation. In the many years of educational software creation only the past few have seen applications designed from the ground-up for these multi-touch

displays leaving many previous programs with potential multi-user benefits left behind in the single-user domain.

Many of these existing systems are based on the inspection and interaction of large data sets, whether they are single, large resolution images or large audio waveforms. JLens provides a conclusive way of converting these existing single-user, single-touch systems into multi-user multi-touch systems by allowing many users to interact with this data by creating individual lenses to navigate and explore the data in a collaborative way.

As the JLens solution was initially presented to solve some of these existing problems it evolved and allowed a way to simplify the information contained in these large data sets by consolidating the data at certain zoom points in a system called context-sensitive zooming. This allowed a way to guide the users into certain areas of interest and the overall effect promotes learning in an educational environment. The final results gained from the evaluation show that JLens is easy to navigate, a useful tool for learning and a suitable method for converting single-user content for a multi-user collaborative environment.

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Appendix – Sample Questionnaire

Single-touch to Multi-touch Software Conversion – Questionnaire

Please spend a short while filling in this questionnaire. Although the answers you give for the multiple choice elements are important please give some more time answering the free-form parts of the questionnaire where you are invited to add **further comments**.

Ease of Use (Please Circle Selected Answer)

1. How would you rate the ease of use of moving and rotating the lens?

Very Easy / ~~Easy~~ / Hard / Very Hard

Further comments

2. How would you rate the ease of use of zooming the lens into a point?

~~Very Easy~~ / Easy / Hard / Very Hard

Further comments

3. How would you rate the ease of use of locking the lens and passing the lens to another user?

~~Very Easy~~ / Easy / Hard / Very Hard

Further comments

4. To what extent do you agree/disagree that collaboration with another user is beneficial for this type of application?

Strongly Agree / Agree / Indifferent / Disagree / Strongly Disagree

Further comments

Please turn over.

Context-sensitive Zooming

Current, traditional interactive systems use pop-up windows to display information to the user.

5. To what extent do you agree/disagree that the ability to **context-zoom** into a point to reveal information **aids** with the flow of the system (when compared to the traditional pop-up window)?

Strongly Agree / Agree / Indifferent / Disagree / Strongly Disagree

Further comments

6. Do you feel direct interaction with a multi-touch surface more engaging with the subject matter than normal keyboard & mouse input?

Yes / No

Further comments

Thank you for taking the time to fill in the questionnaire.
